Climate Variability and Change in the Atlantic Sector

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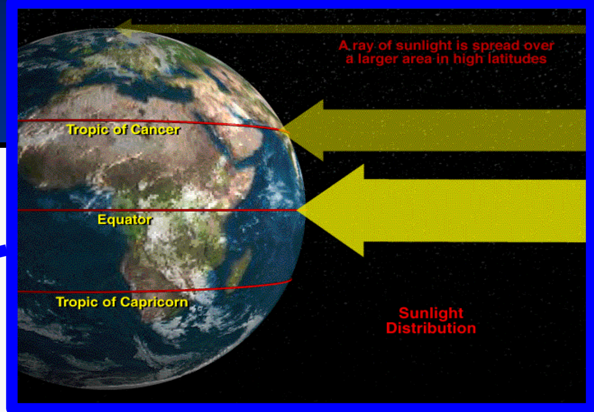
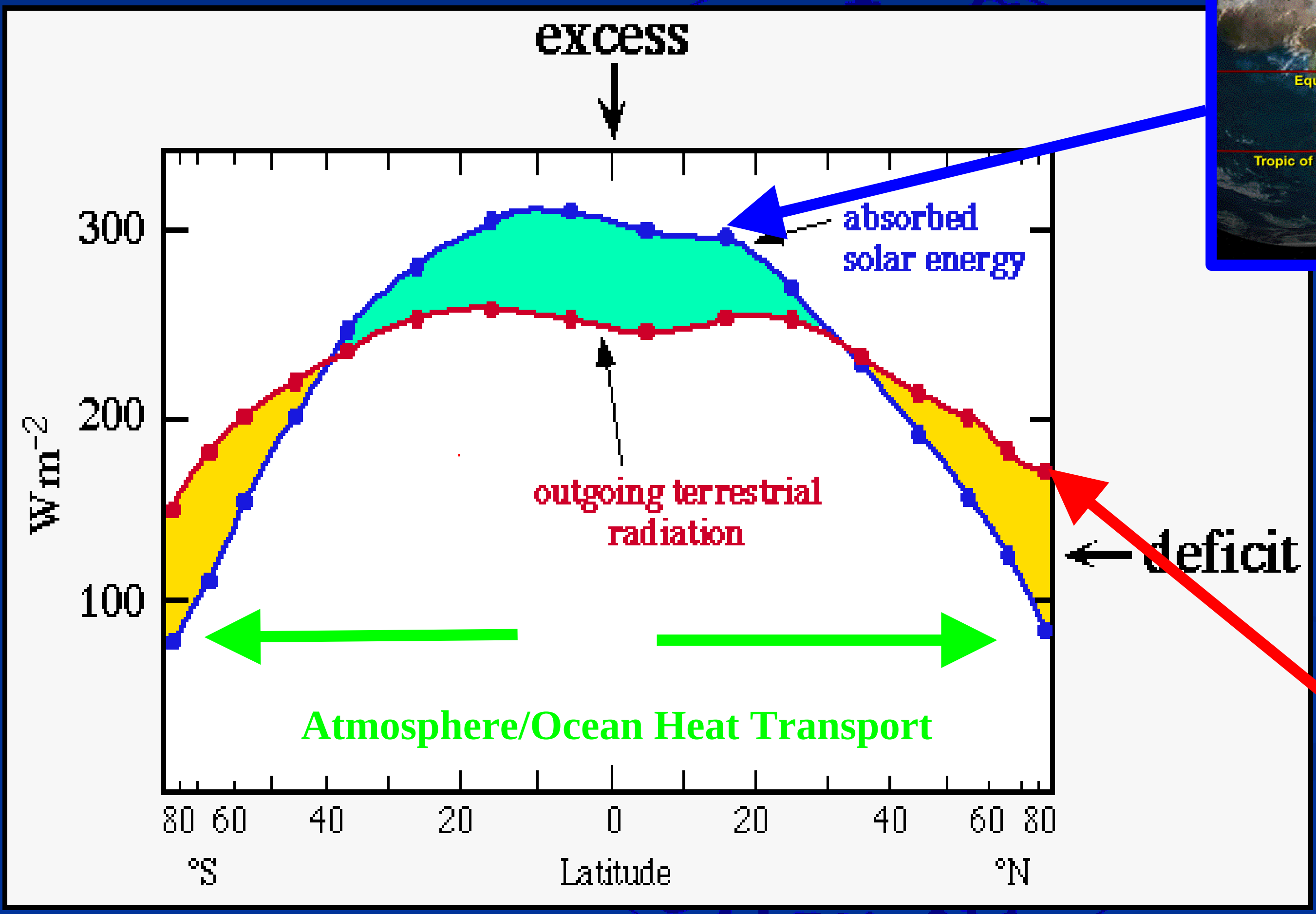
Outline

- Background
- Observed variability and change in the Atlantic Sector
- Where is the Predictability?
- Challenges for the future

Where does the energy come from to drive atmospheric and ocean circulation?

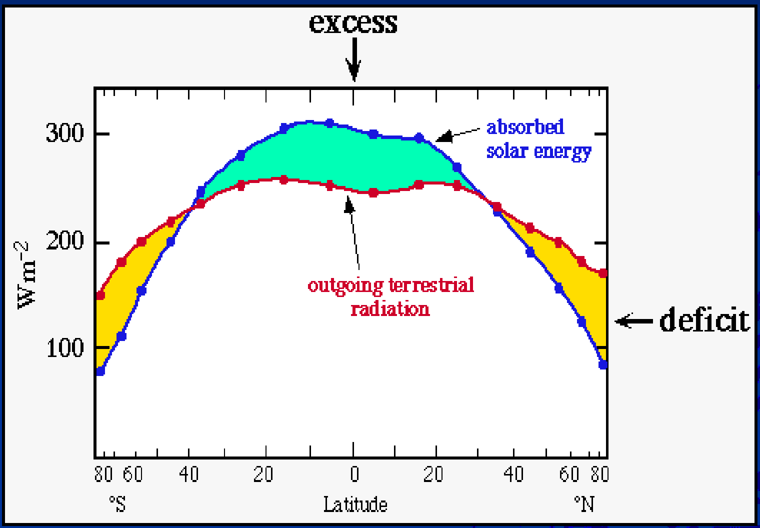
Radiation Balance
Top of the Atmosphere

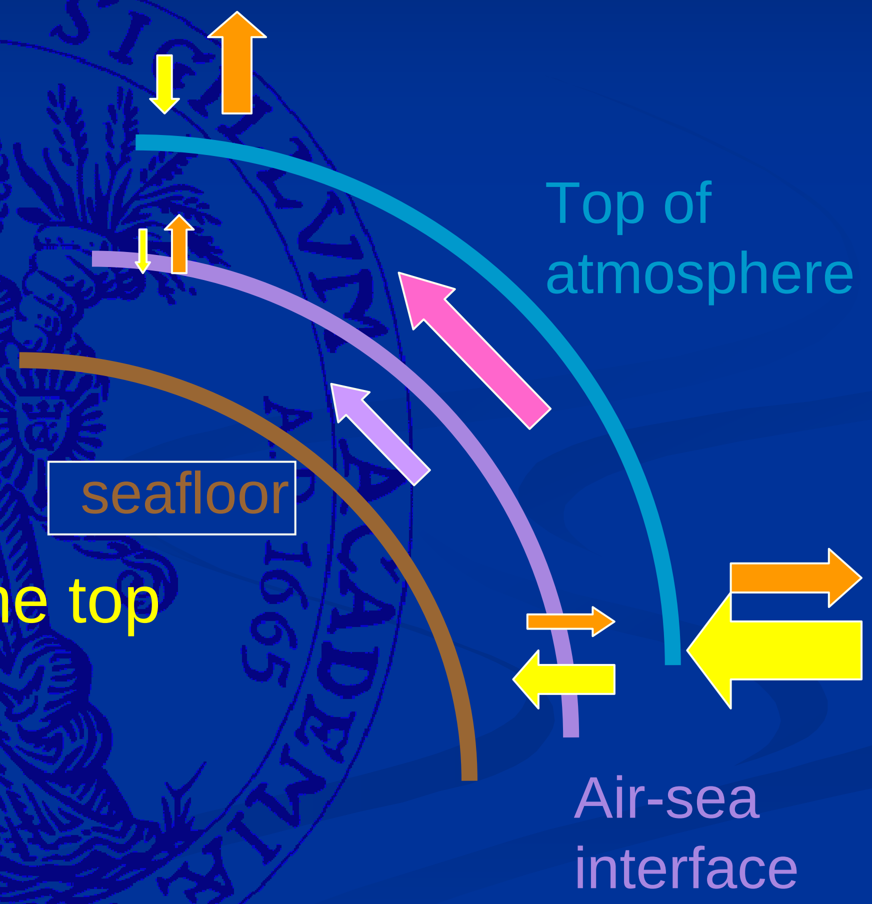




$$I \sim \sigma T^4$$

General Atmosphere Ocean Circulation
The surface energy balance





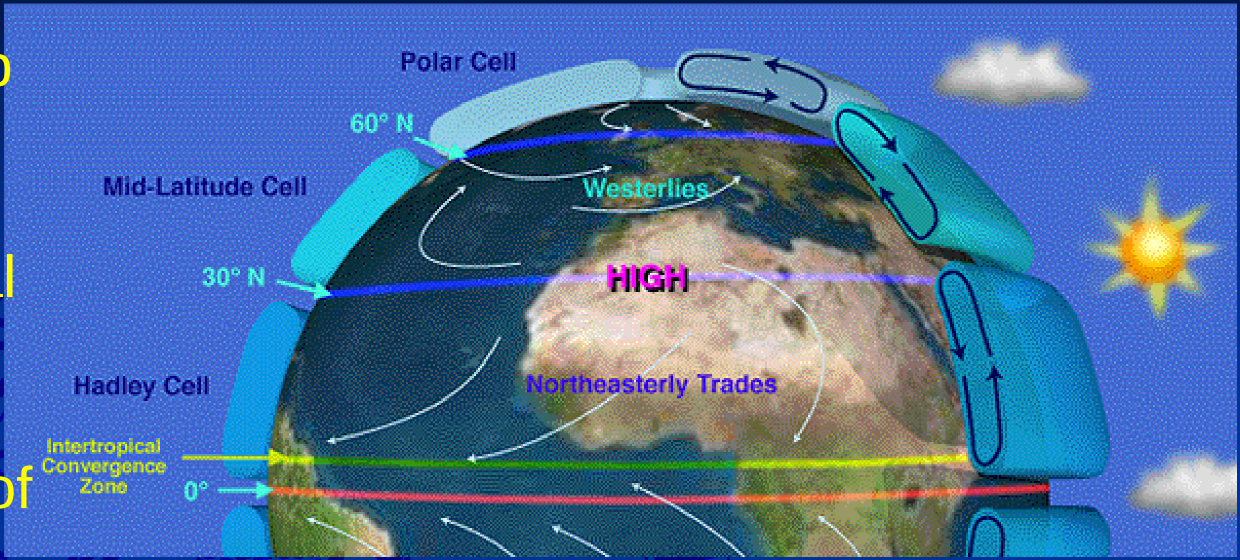
Imbalance of energy flux at the top can be balanced by:

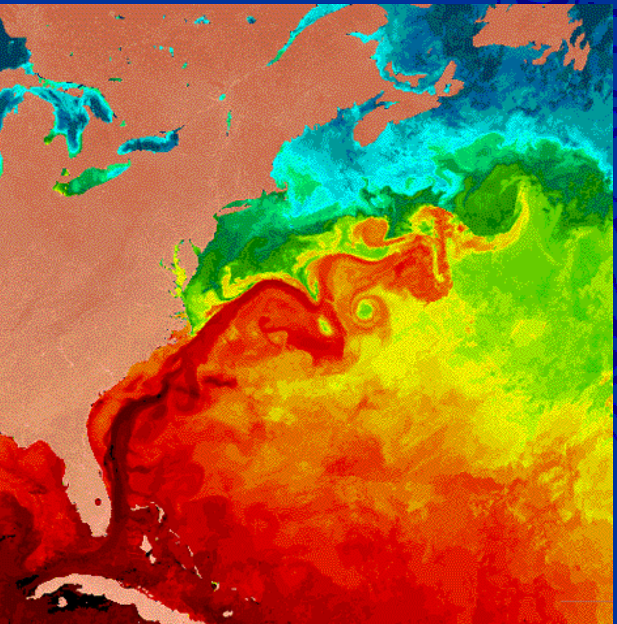
Atmospheric Heat Transport

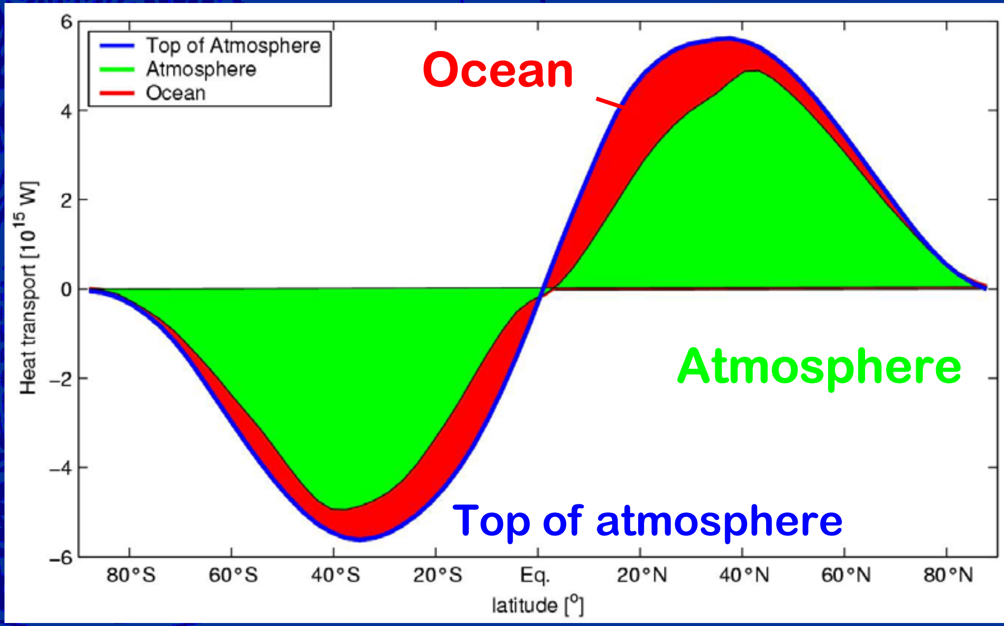
Oceanic Heat Transport

Dynamical Heat Transport

The imbalance of the top of the atmosphere radiation implies that there must be an internal heat transport by the combined action of ocean and atmosphere of ~6 10^{15} W 30°N/S.







Point 1

- Regional imbalances of the incoming and outgoing radiation result in a dynamical heat transport (fluid moves).

- This heat transport is split between the ocean and atmosphere.

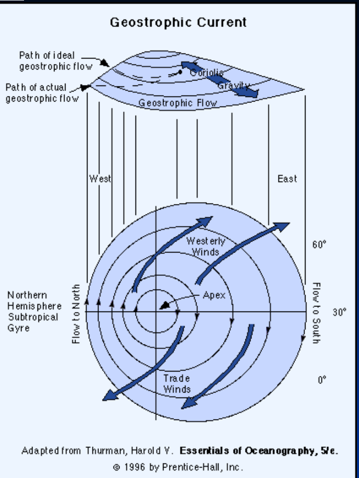
- The atmosphere is largely heated from below and cooled throughout thus to first order a heat engine.
- Is this also true for the ocean?

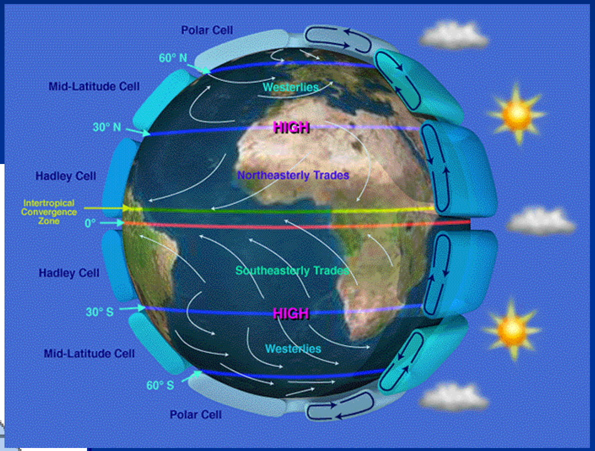
Are there different “types” of ocean circulation?

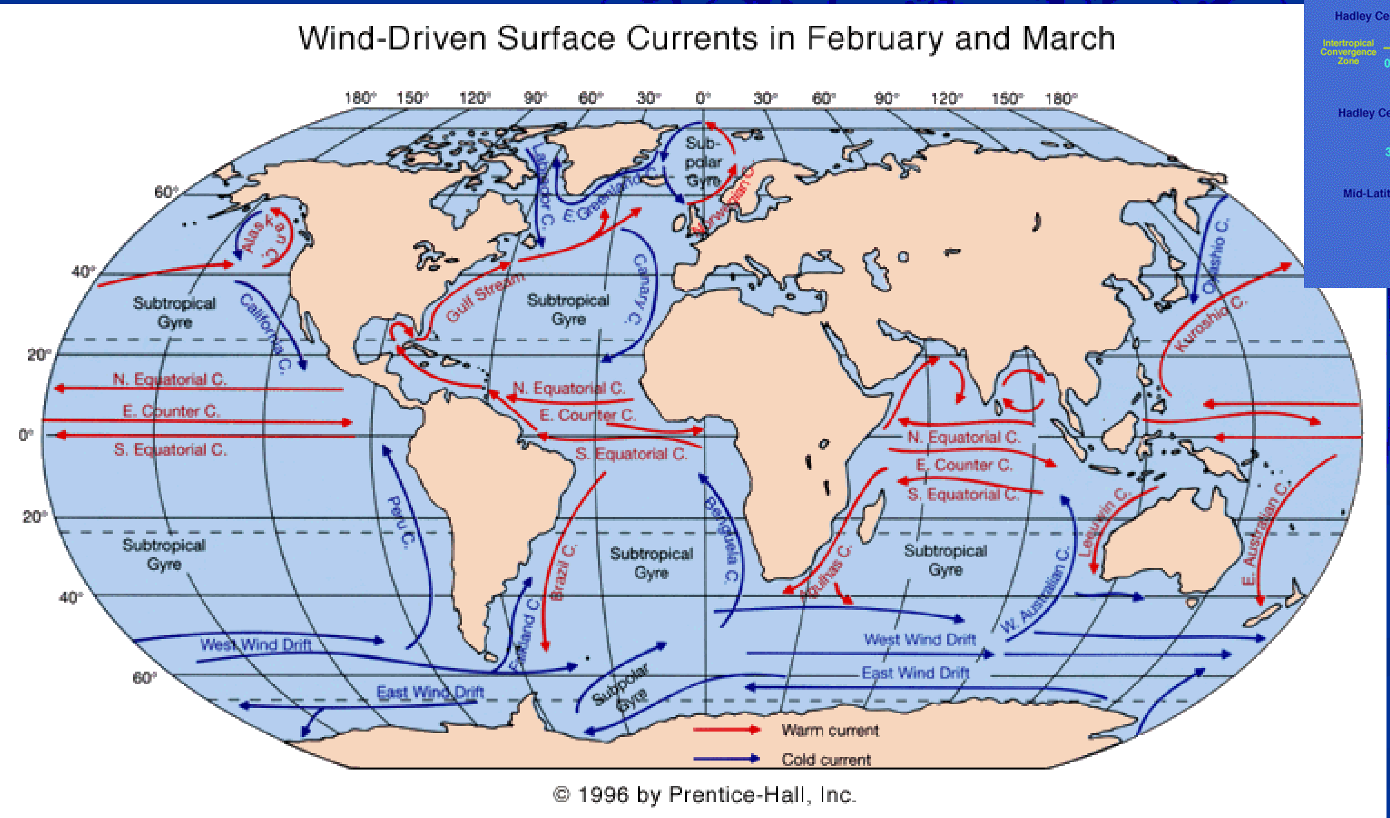
Ocean Circulation

- Ocean circulation is produced by:
- 1) the wind stress acting on the sea surface (mechanical forcing) and
- 2) by buoyancy (heat and freshwater) fluxes between the ocean and atmosphere (buoyancy forcing).
- The former induces the wind driven ocean circulation, the latter the thermohaline (or buoyancy) circulation.
- Most currents are forced by the combined action and thus this separation is of limited use.

Large Scale Wind Driven Ocean Circulation





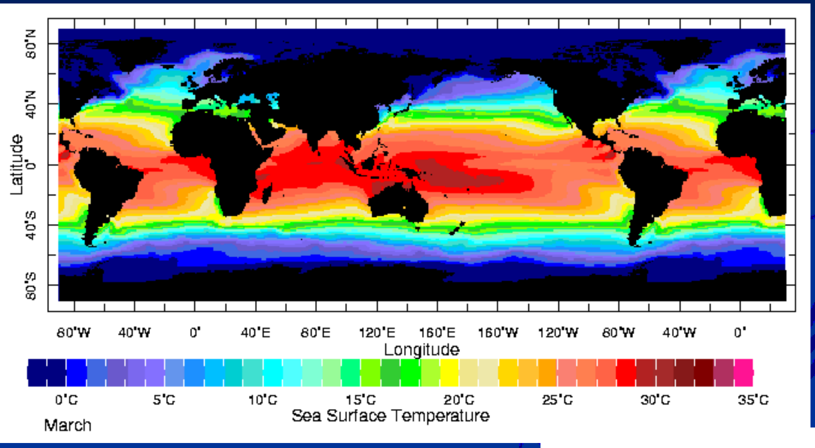


Buoyancy driven circulation…

(is it really…)

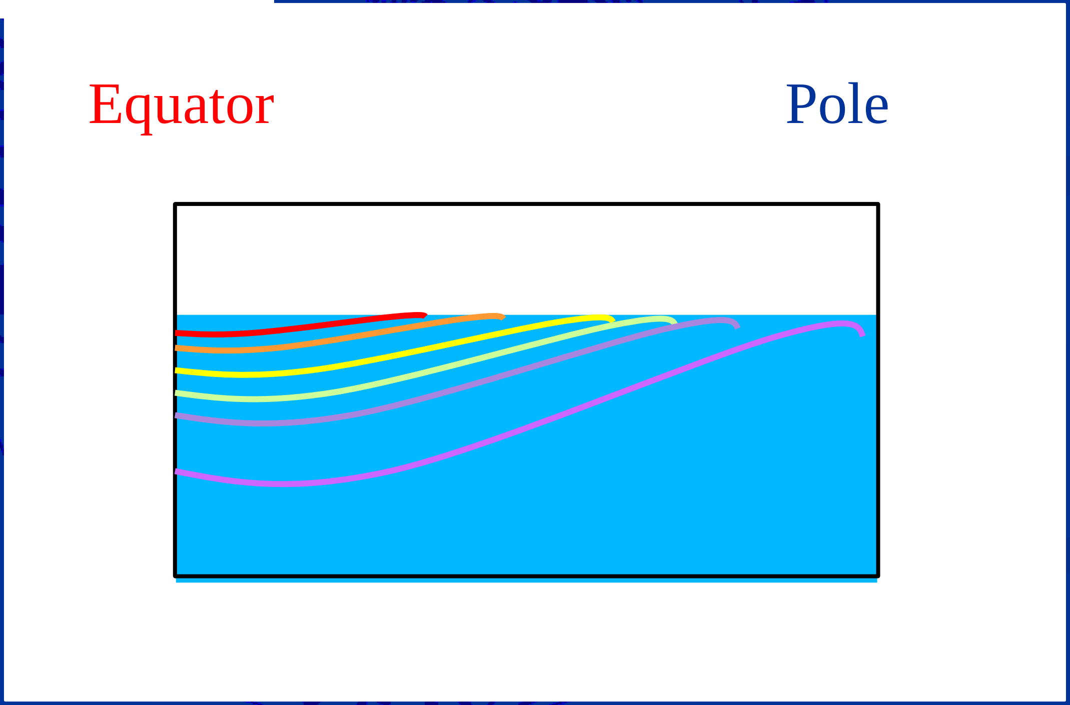
[the buoyancy flux depends on heat and freshwater fluxes, thus the name thermo-haline circulation]

Ocean circulation simulation in "fish tank"



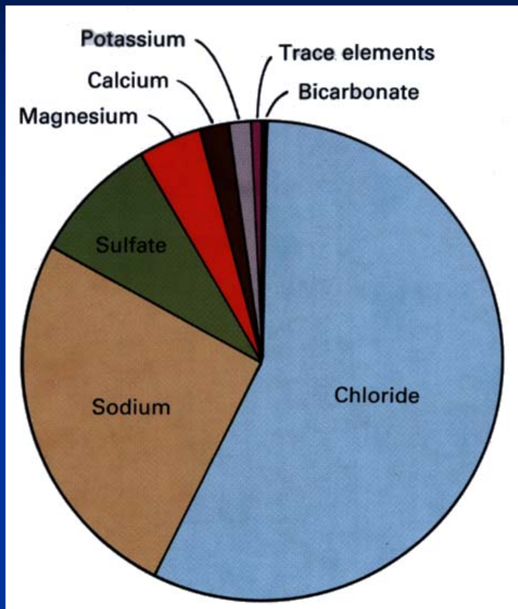
The tough part is to get the warm water down…

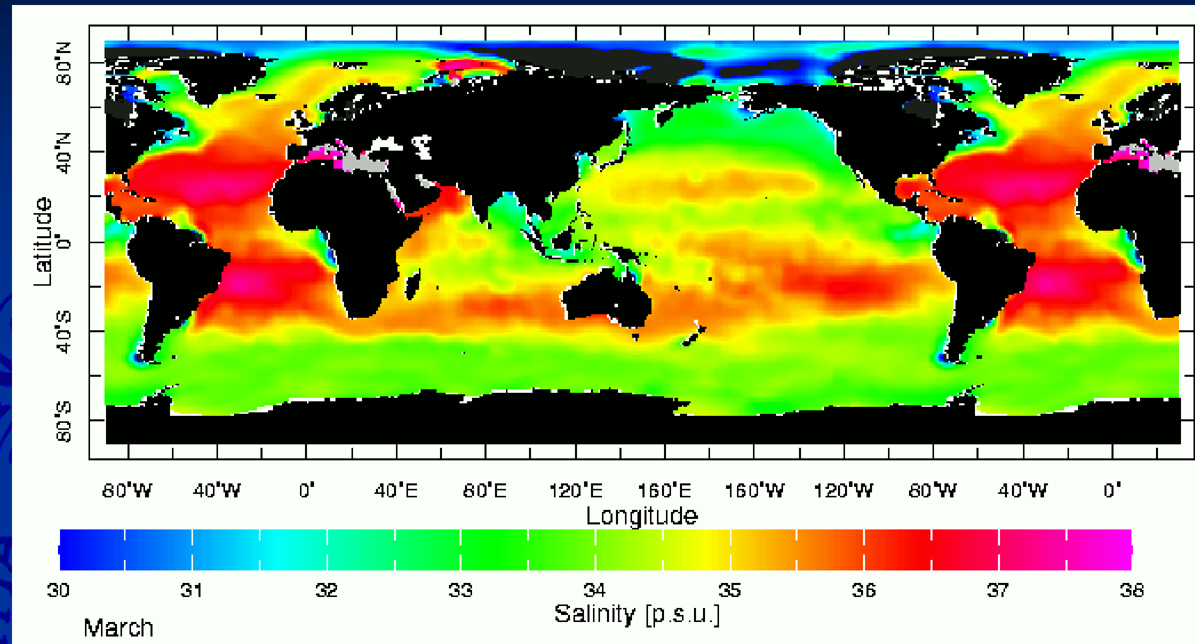
Thus mechanical forcing is key!



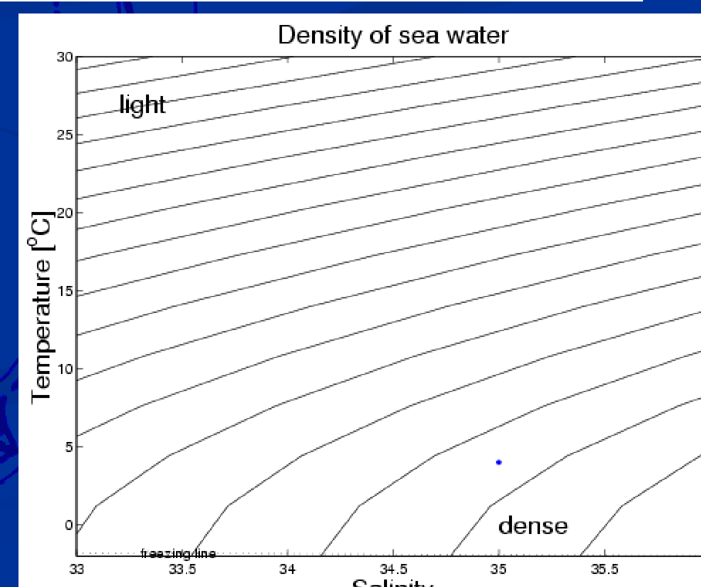
But how about the effect of the earth's rotation ?

Ocean Salinity





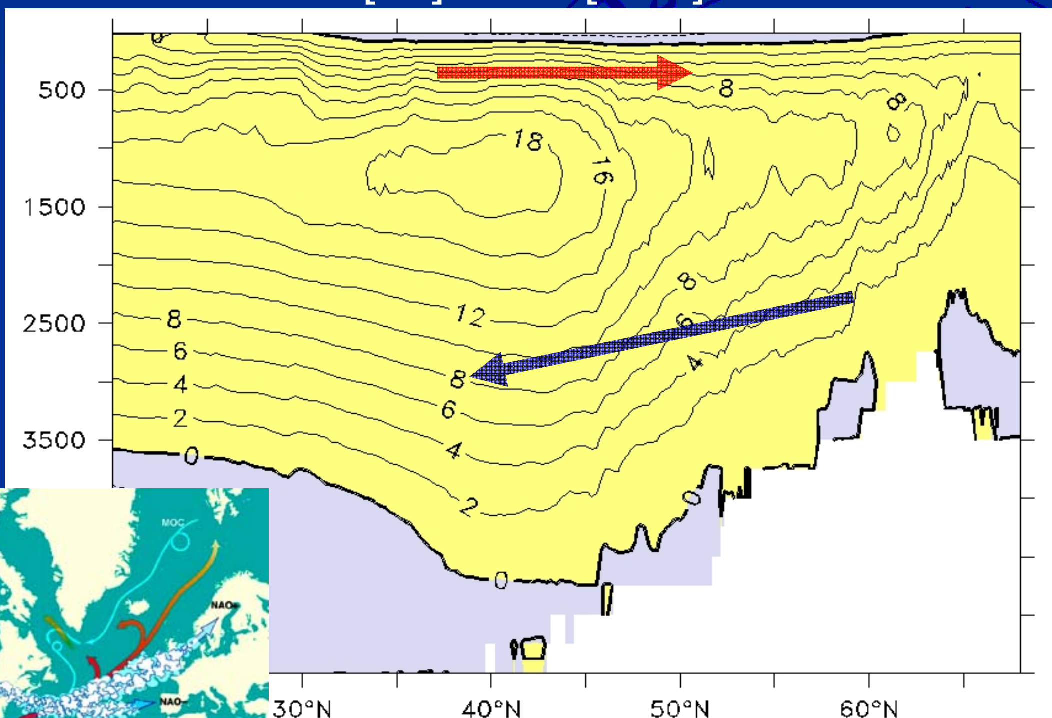
- The more saline, the denser the sea water
- Density of sea water is a (nonlinear) function of temperature and salinity (and pressure), all play an important role.



How does the global overturning circulation look like?

Meridional Overturning Circulation MOC

Model basd mean overturning circulation (Sv)
1 [Sv] = 10^6 [m^3/s]



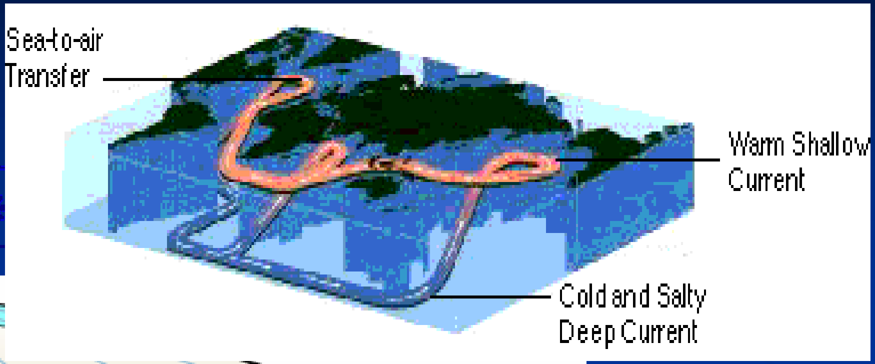
One can zonally average the north-southward circulation and express is as a stream function

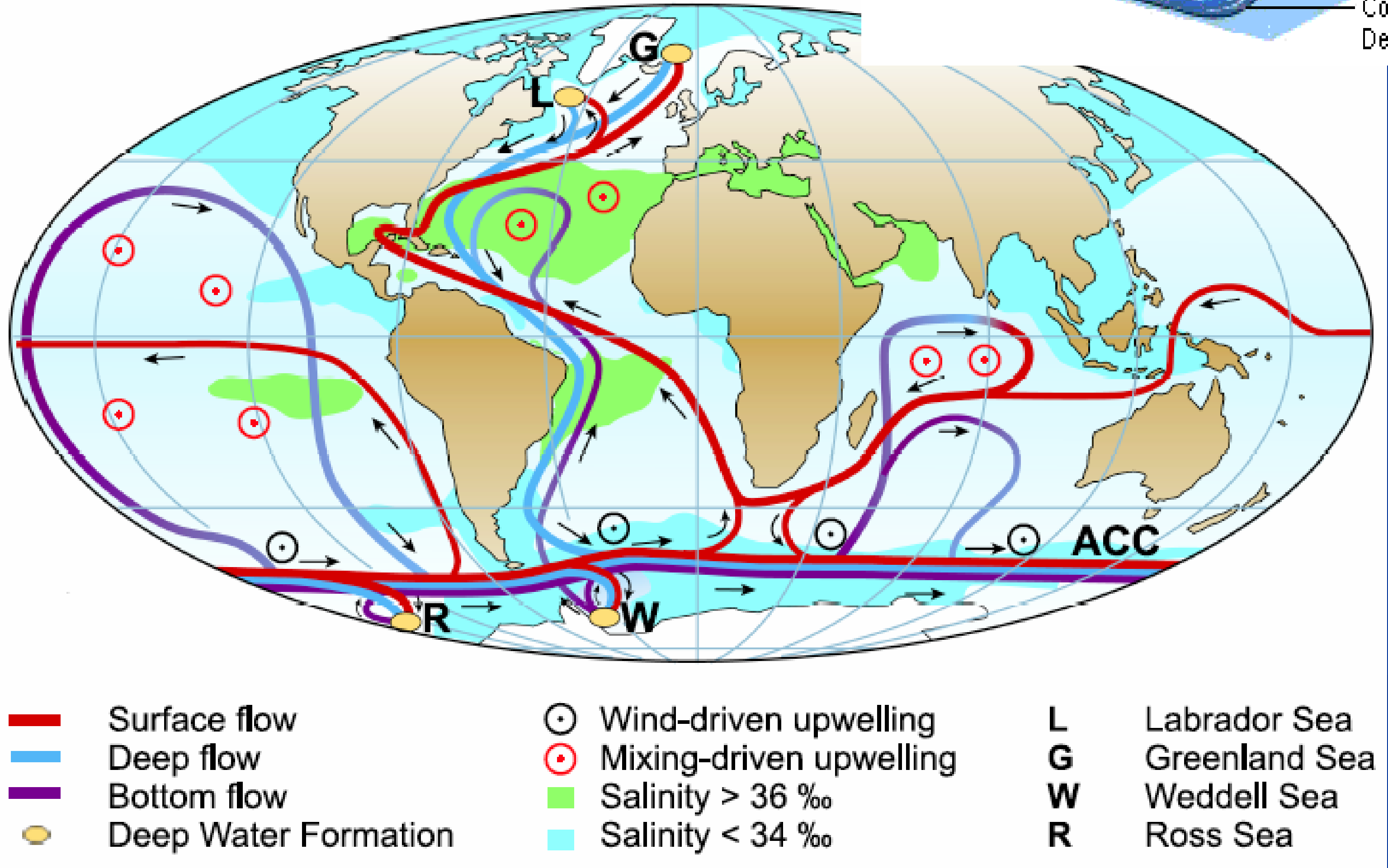
The strength of the maximum of that stream function is often used as an indicator.

Todays numbers are 16-20 Sv in the Atlantic Sector.

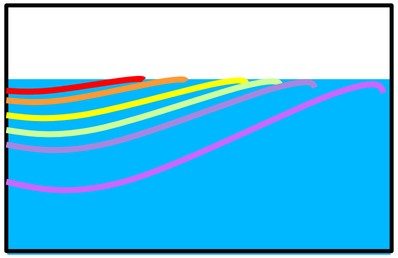
Meridional Overturnig Circulation

The grand ocean “conveyor”

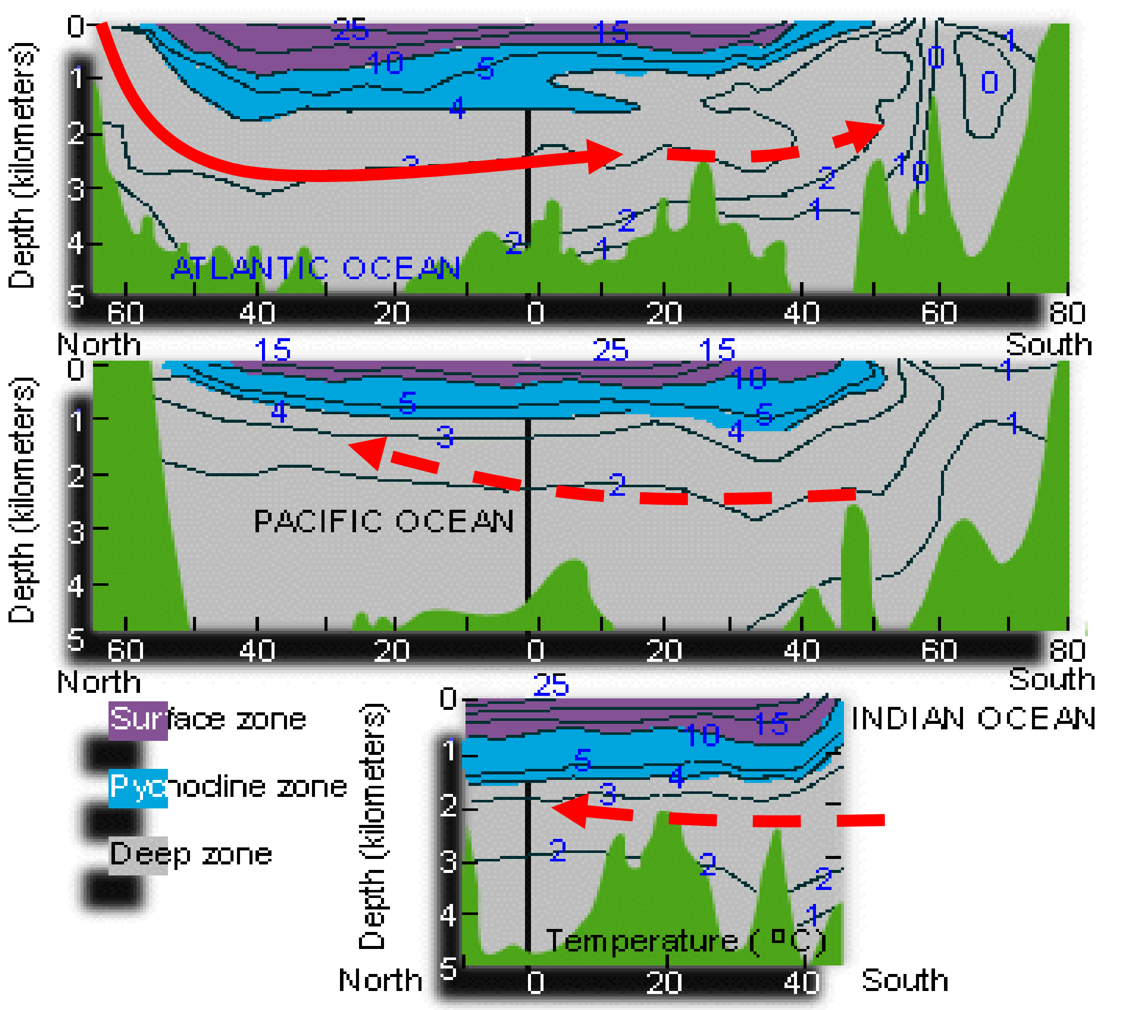




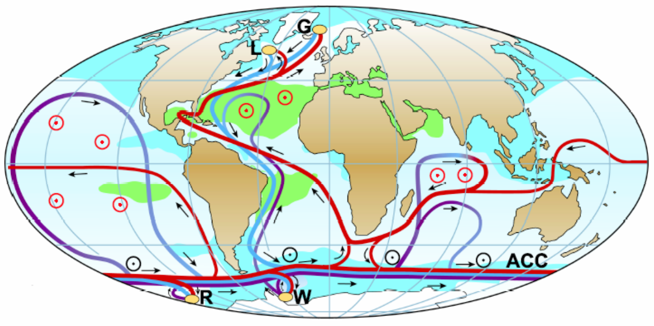
(Kuhlbrodt et al 2005)

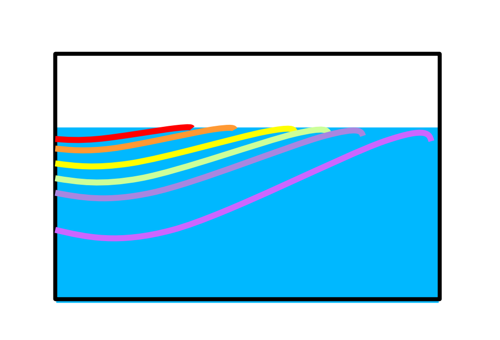


Atlantic Overturning (A-MOC)

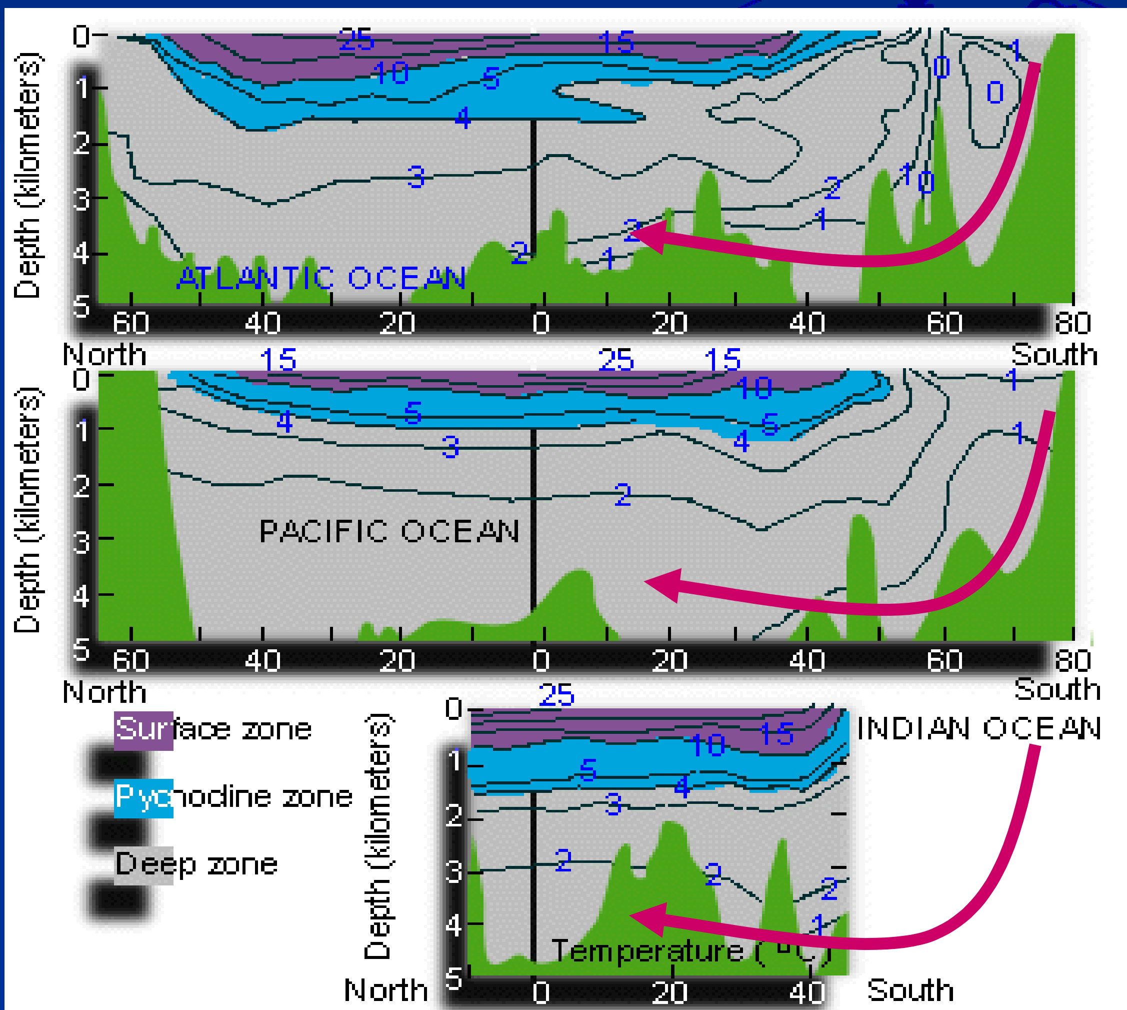


- North Atlantic Deep Water
- Antarctic Bottom Water

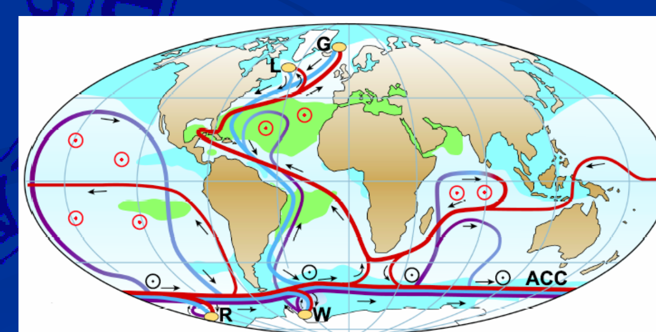




Southern Overturning (S-MOC)



- North Atlantic Deep Water
- Antarctic Bottom Water



Point 2

• The ocean circulation is driven by the combined action of wind and buoyancy (thermo - haline) forcing.

• The configuration of the continents and associated atmospheric heat and fresh water transport result in a large global circulation connecting all major ocean basins.
[Atlantic Sector key]

Outline

- Background
- Observed variability and change in the Atlantic Sector
- Where is the Predictability?
- Challenges for the future

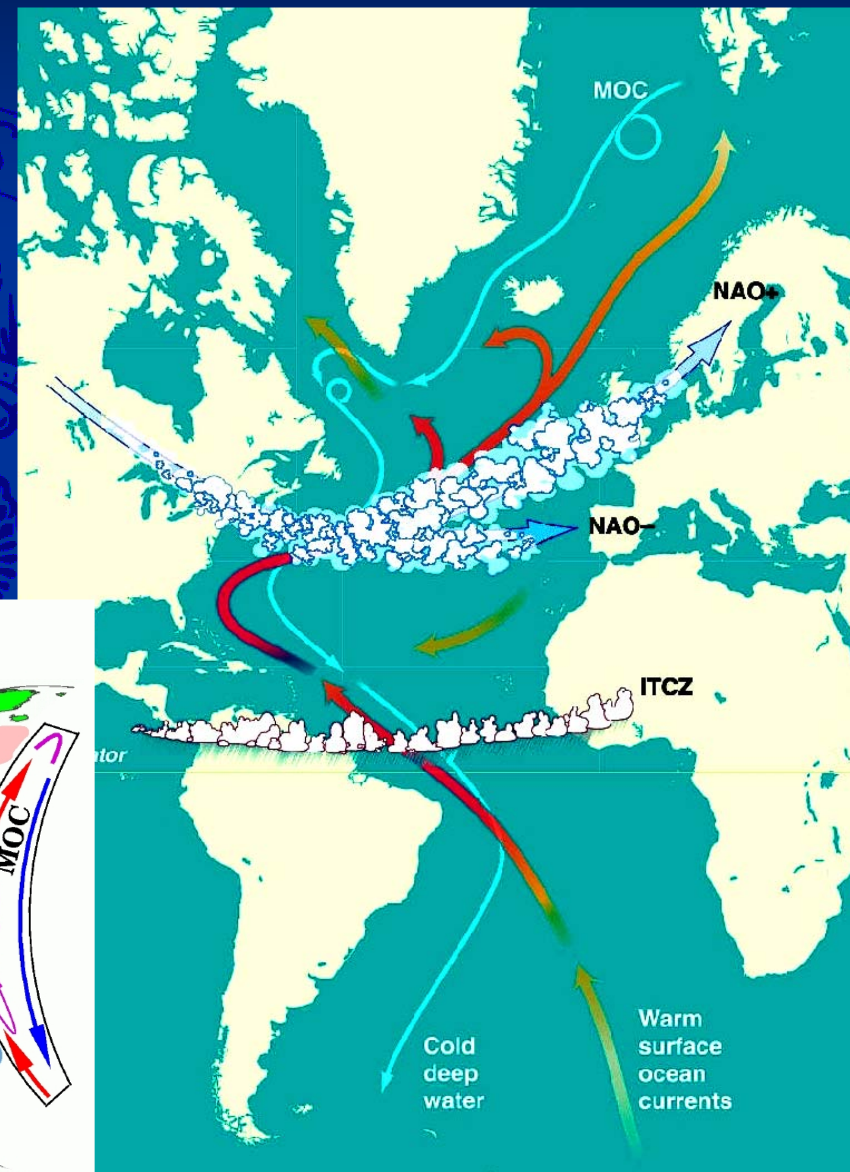
Atlantic Sector Phenomena

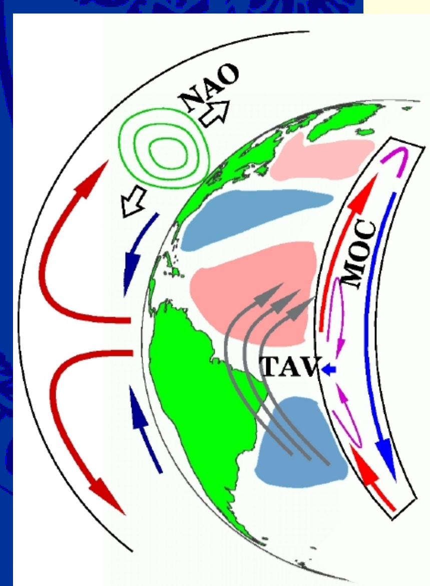
- North Atlantic Oscillation

- Meridional Overturning in the Ocean

- Tropical Atlantic Variability

- Interactions with each other and/or other climate forcings including ENSO and ACC

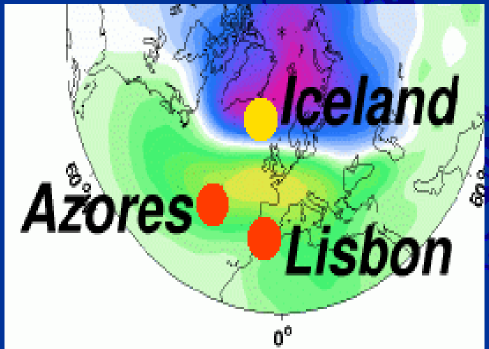


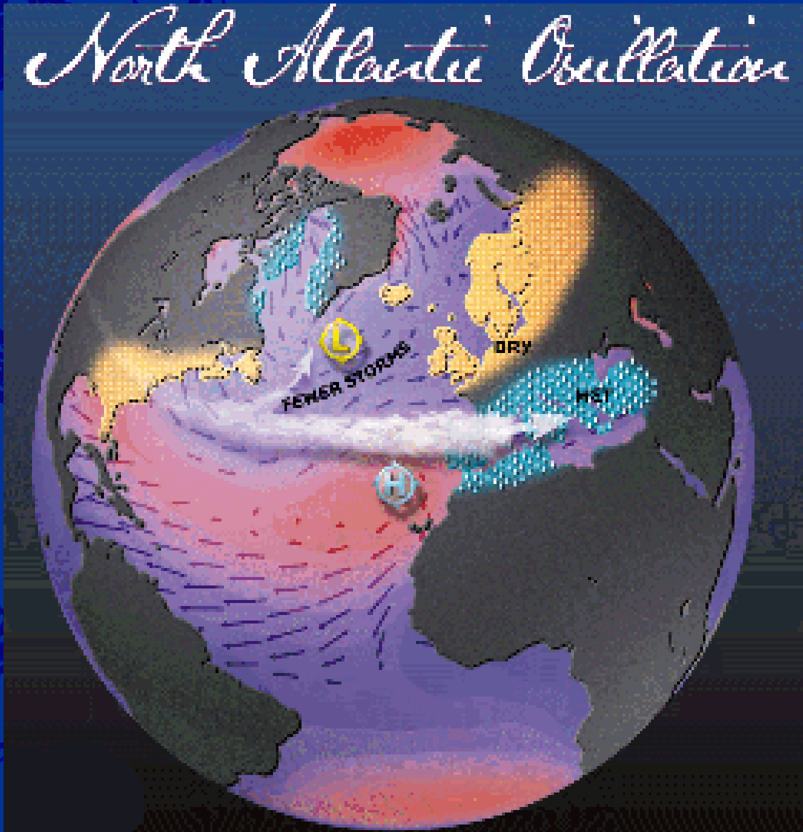


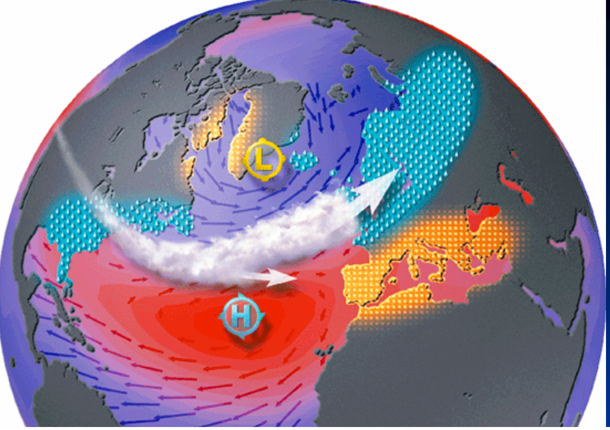
The North Atlantic Oscillation

Changes in the Subpolar to Subtropical Atmospheric Pressure Difference lead to:

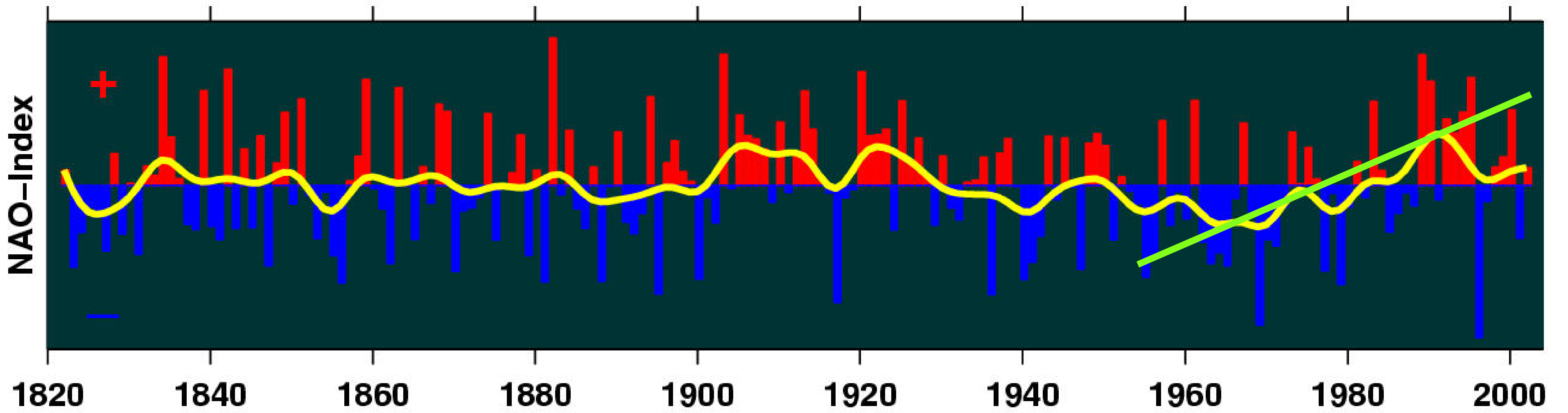
- Changes in strength and position of the westerly winds (storm track)
- Phase can be described by a see level pressure based index



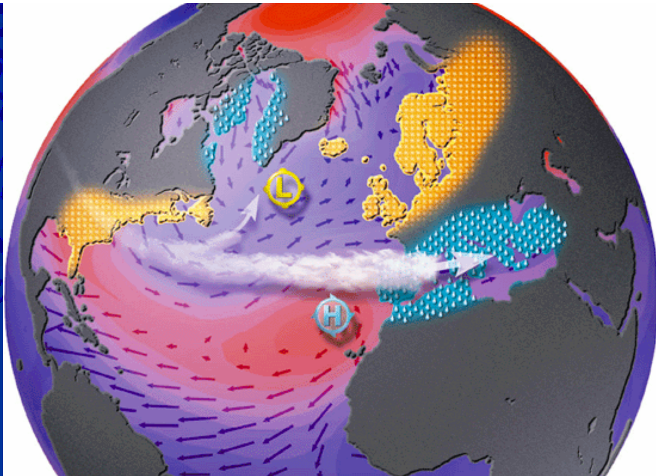




The North Atlantic Oscillation Index



Is the "apparent" trend of the last decades significant and /or explainable ?



Impacts of the North Atlantic Oscillation

IFM-GEOMAR
Leibniz-Institut für Meereswissenschaften an der Universität Kiel

CLIVAR — Climate Variability & Predictability — World Climate Research Programme

IMPACTS ASSOCIATED WITH A POSITIVE NAO YEAR.

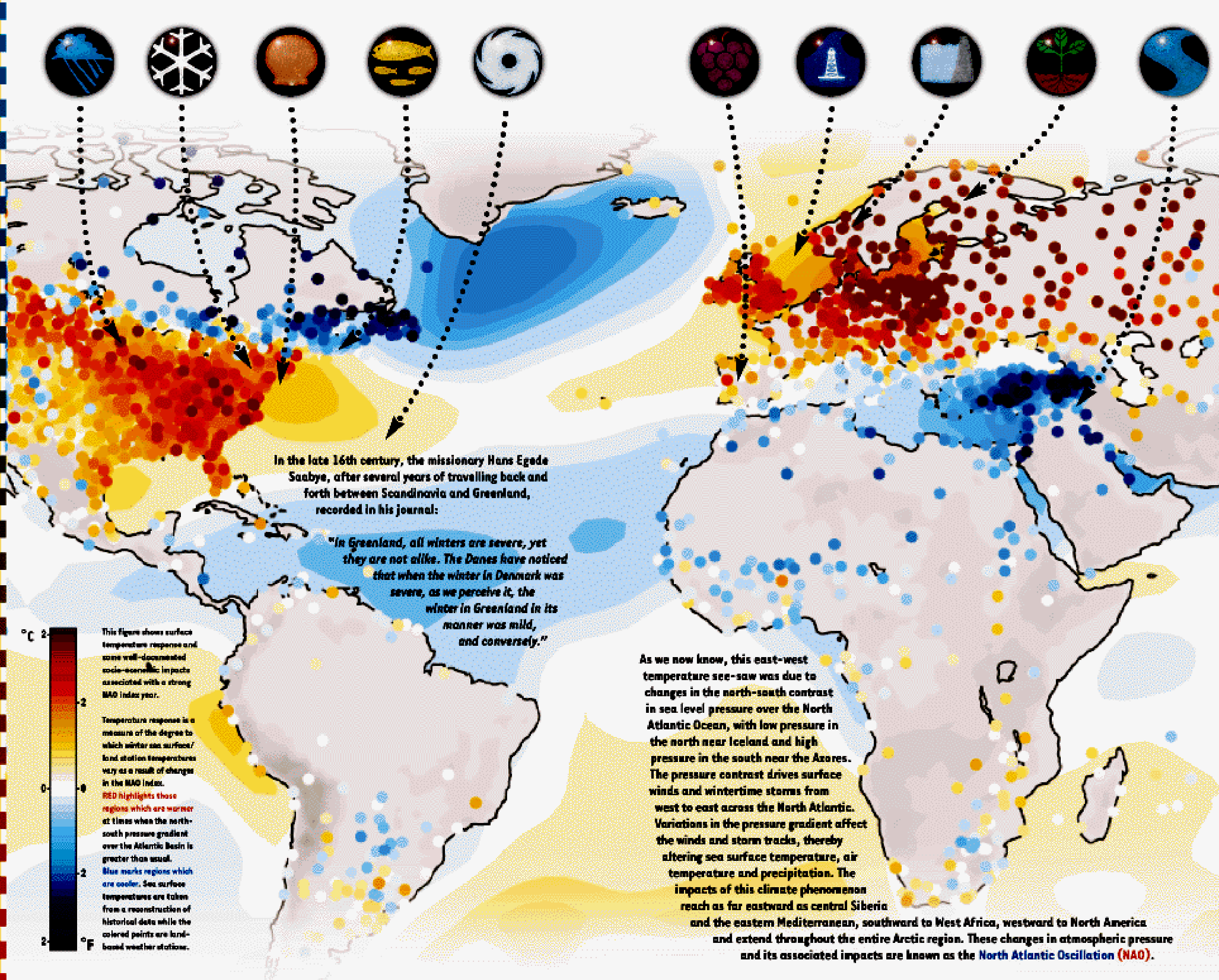
NORTHEASTERN US
Increased temperature results in decreased number of snow days

NORTH SEA
Increased wave height affects safety of oil rigs and their operators

NORWAY
Surplus water in hydroelectric reservoirs provides potential for selling surplus electricity

SCANDINAVIA
Length of the plant growth season is lengthened by 20 days

CENTRAL US
Increased precipitation and river runoff



IMPACTS ASSOCIATED WITH A NEGATIVE NAO YEAR.

TROPICAL ATLANTIC/GULF COAST
Warmer sea surface temperatures cause increases in number and strength of hurricanes

ATLANTIC
Increased growth and recruitment of Northern Cod

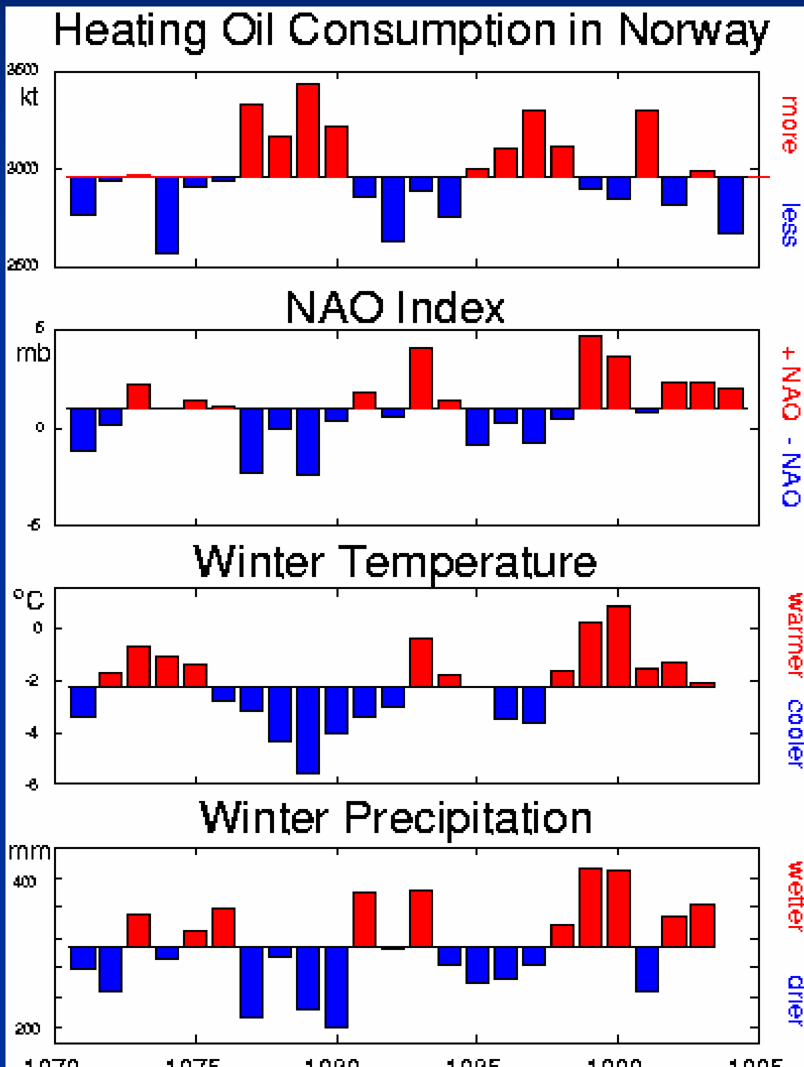
EASTERN LONG ISLAND
Decreased "brown tide" events increase scallop harvests

PORTUGAL & SPAIN
Increased grape and olive harvests

TURKEY
Increased precipitation and streamflow in the Tigris-Euphrates River Basin

NAO and Energy in Norway

Jessica Cherry
Martin Visbeck



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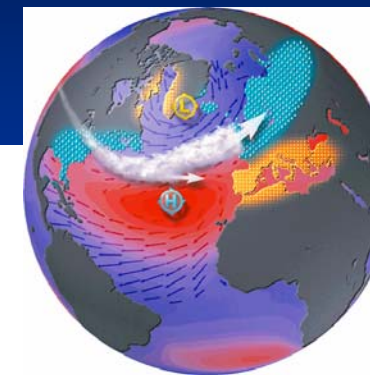
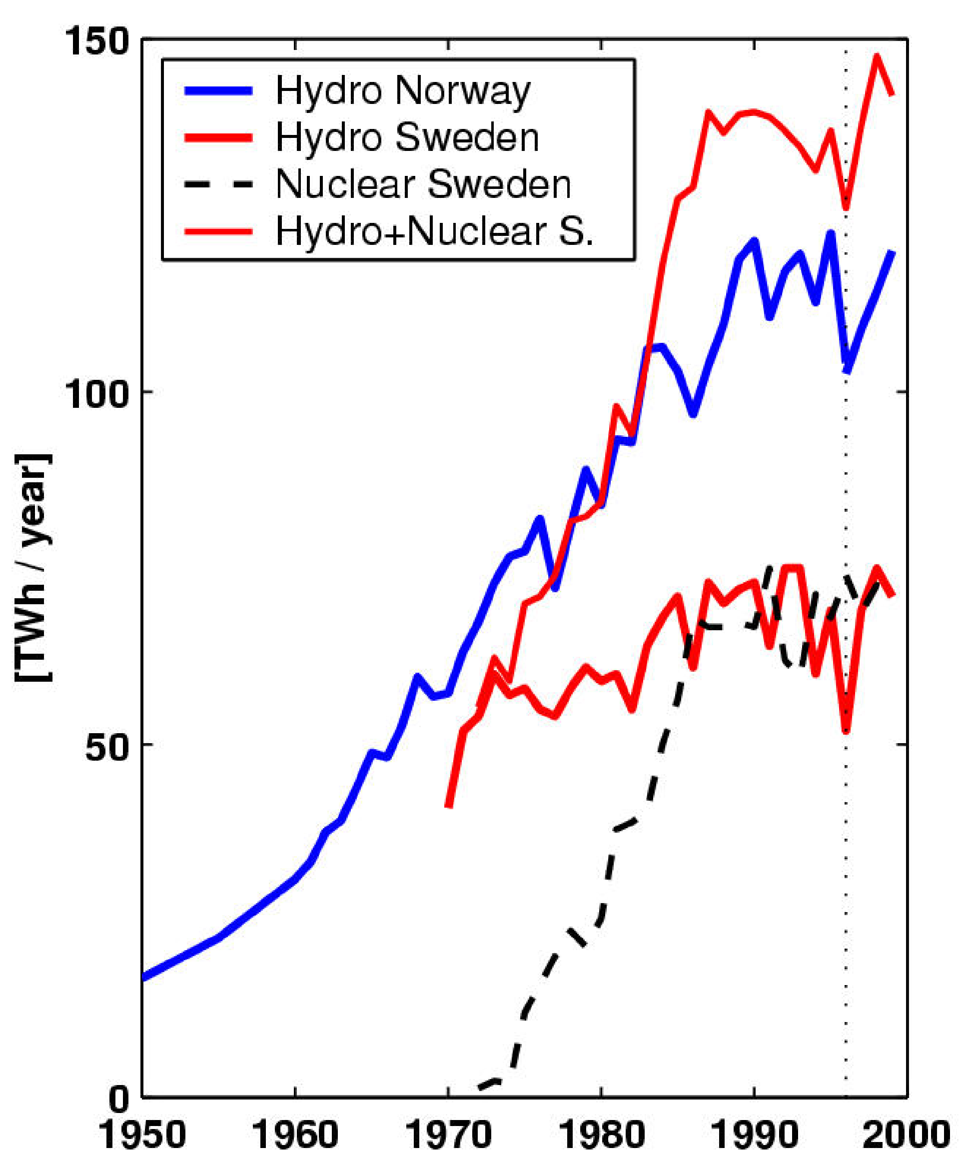
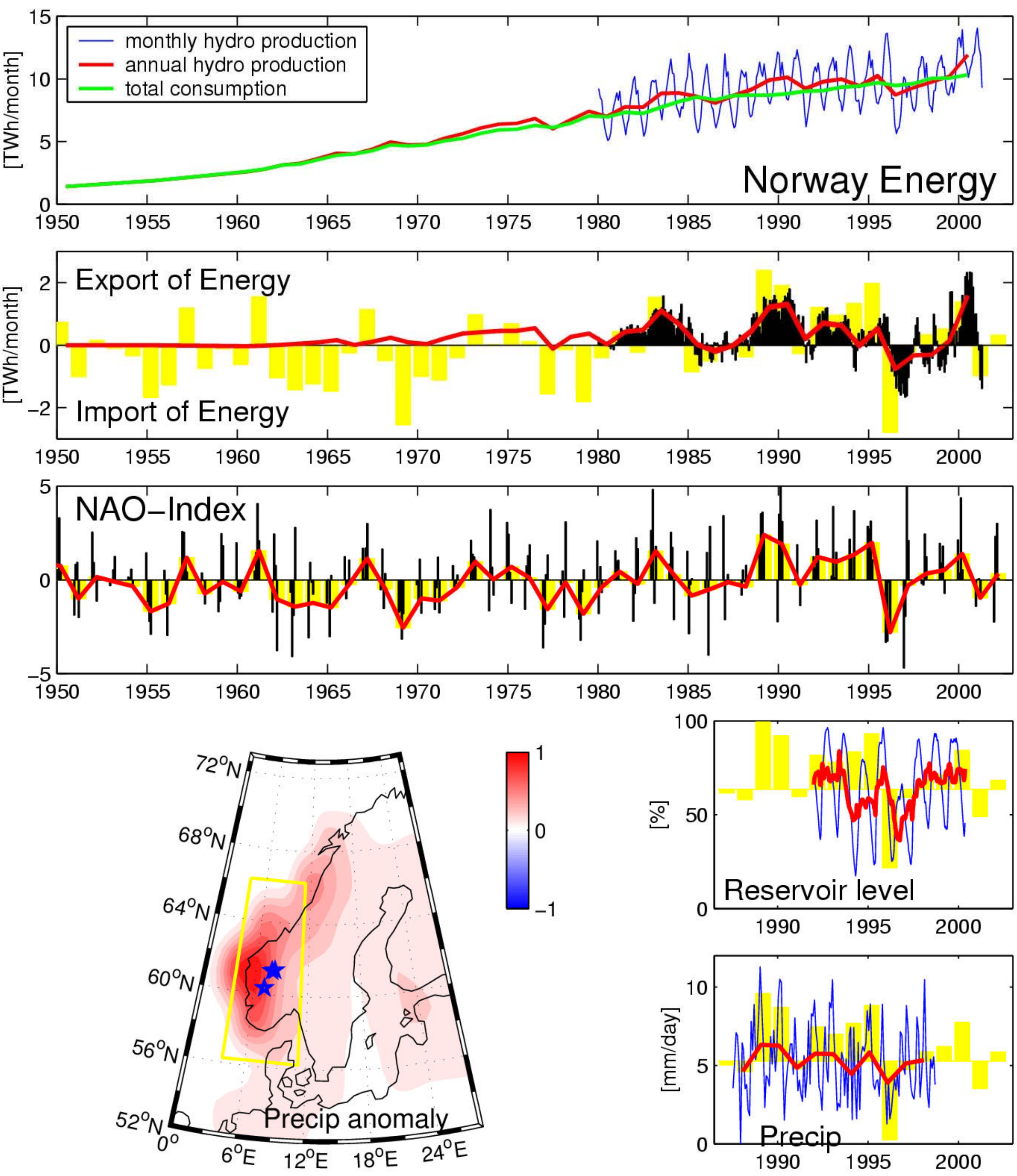


Energy Production in Norway and Sweden



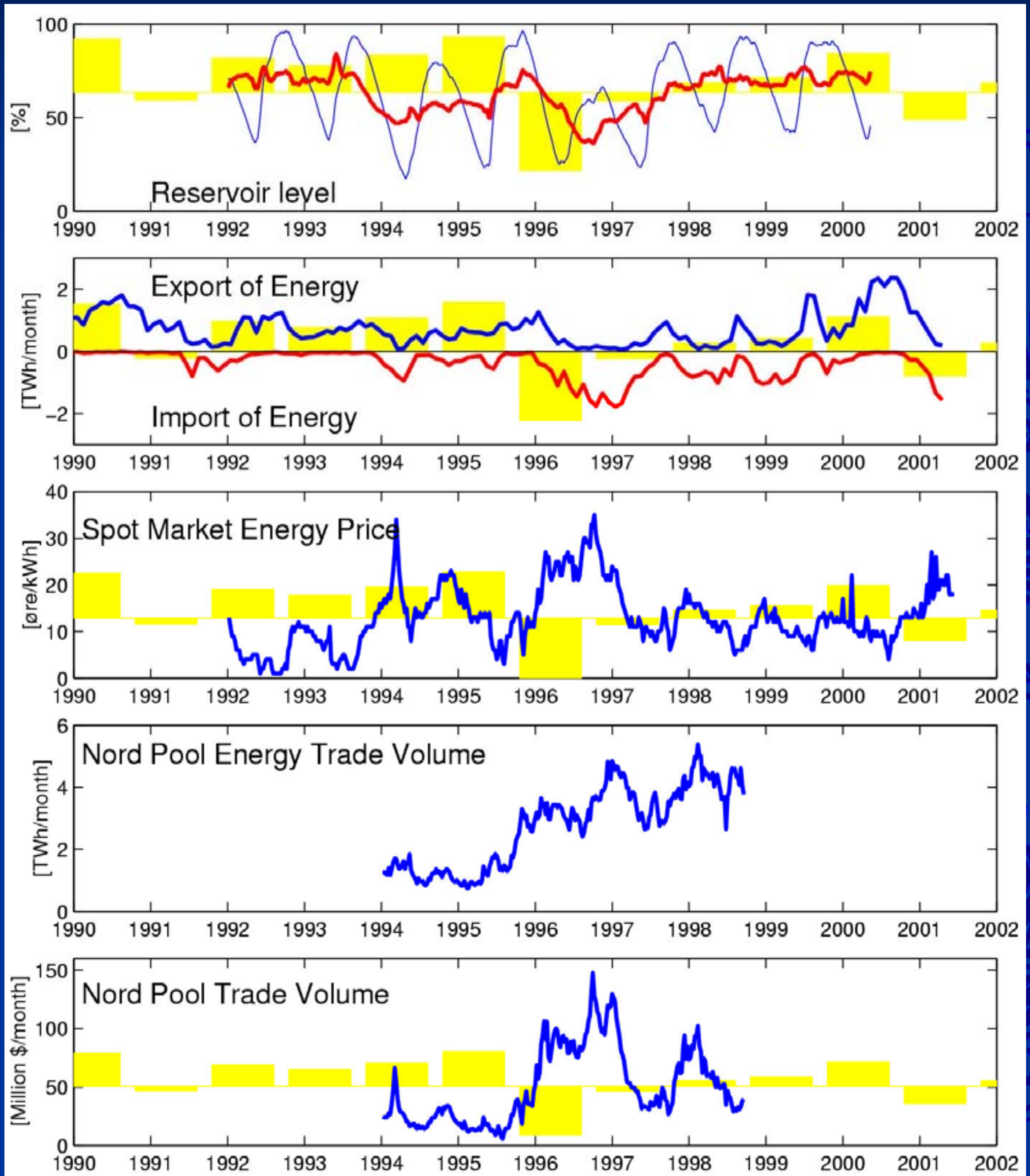
- Hydroelectric energy provides 95% of the electric energy for Norway.
- Sweden uses 50% nuclear energy.



While energy production and consumption have a large trend, the difference is well correlated with the NAO.

The reason is that precipitation and reservoir level are correlated with the NAO

The North Atlantic Oscillation Index Impact on Energy in Norway



- During the shift in the NAO index (1995 - 1996).
- Energy trading raise to levels of $120 Million per month
- Energy shortage gave sharp rise to trade price in spot market.

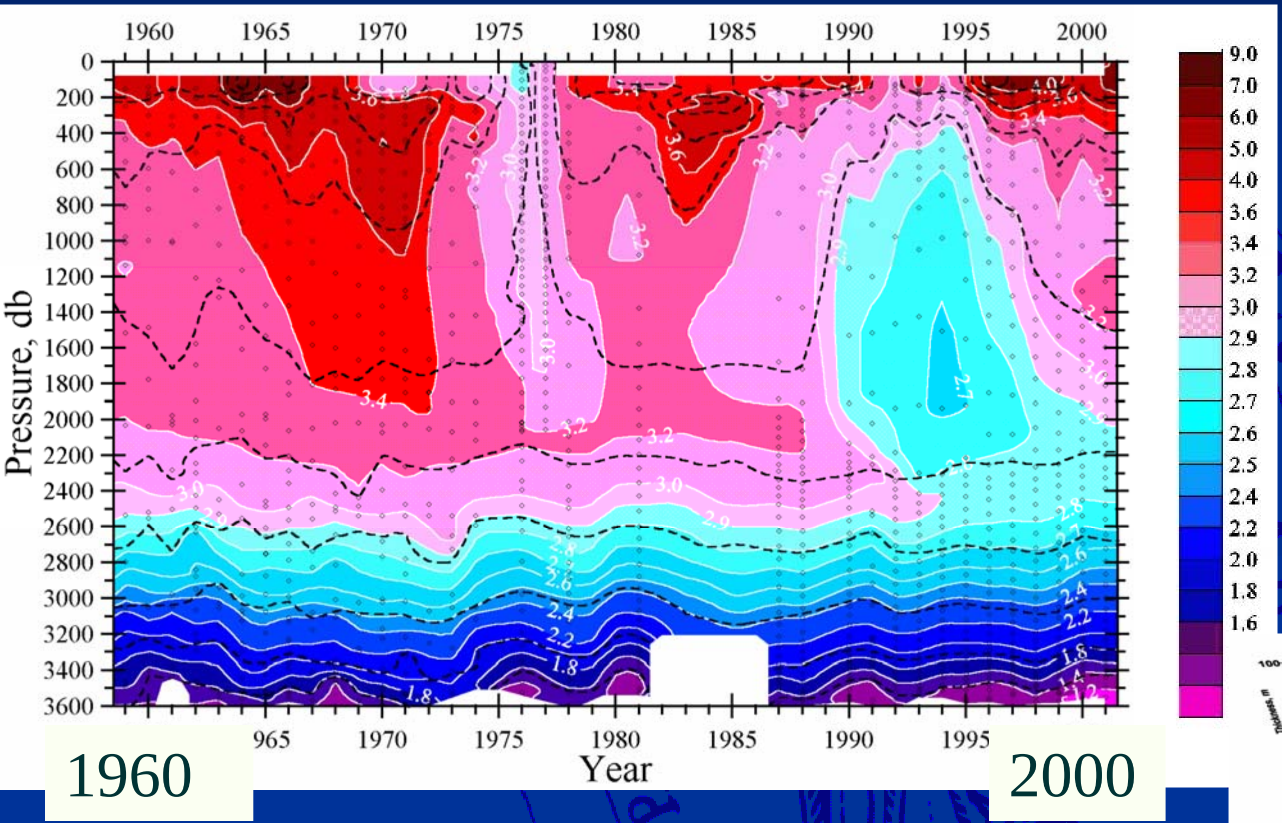
Point 3

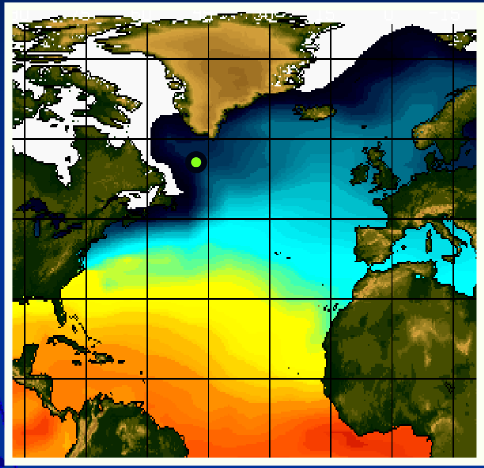
- Some Climate Phenomena have well documented impacts on energy production / consumption

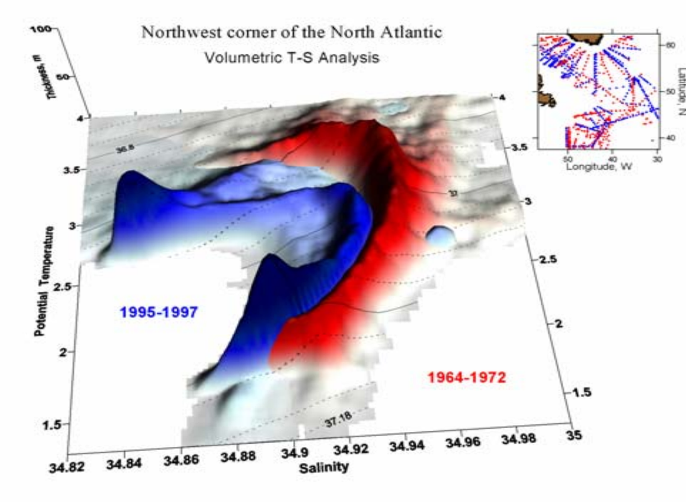
- However, most of the times the correlations are not so obvious and masked by other economic forces

- A better understanding of the potential range of variability will help for future energy supply/demand planning.

Observed Temperature Change in the Subpolar North Atlantic due to NAO?

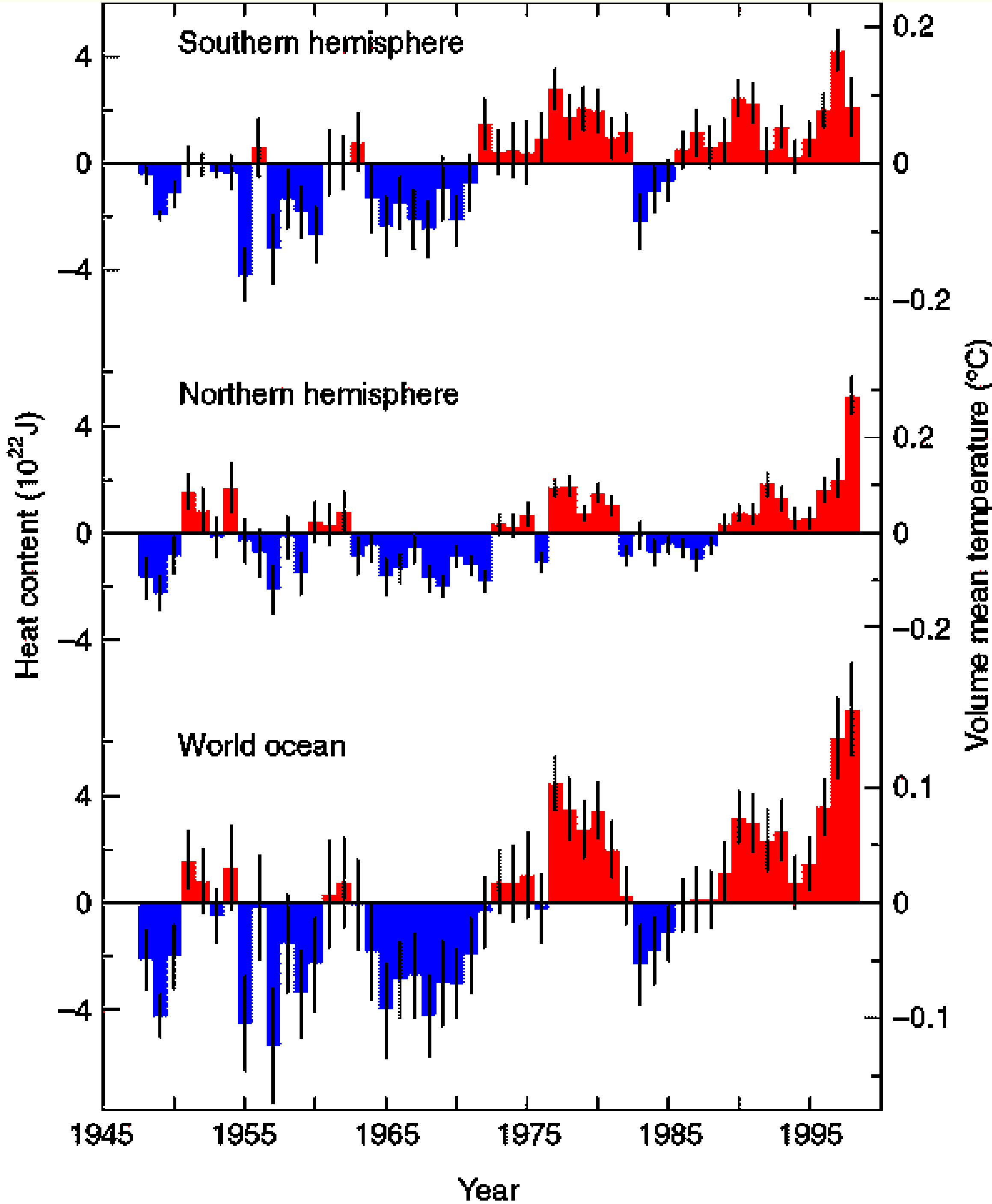






Time-series for 1938 to 2001 of ocean temperatures in the Labrador Sea.

(Yashavaev, BOI pers. comm. 2002)

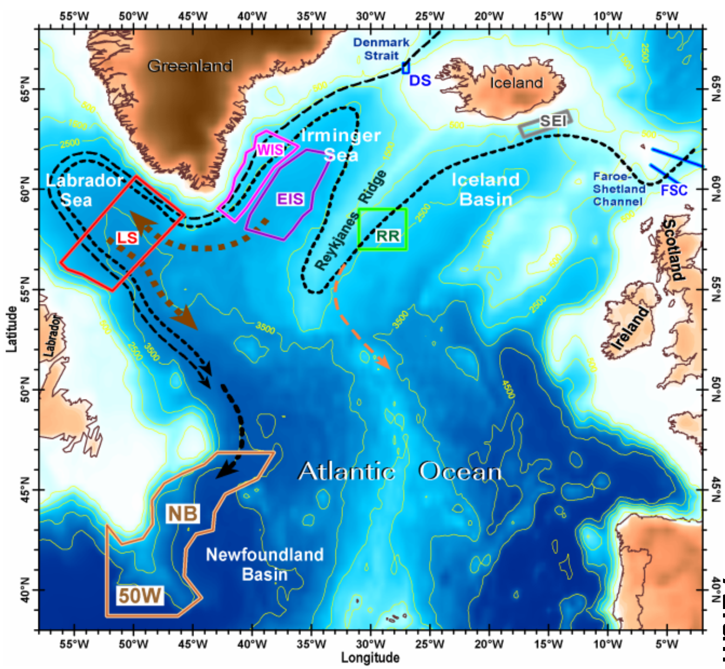


Heat content change

Time-series for 1948 to 1998 of ocean heat content anomalies in the upper 300 m for the two hemispheres and the global ocean.

Note that 1.5 x 10^{22} J equals 1 W / (year m^2) averaged over the entire surface of the earth. Vertical lines through each yearly estimate are ± one standard error .

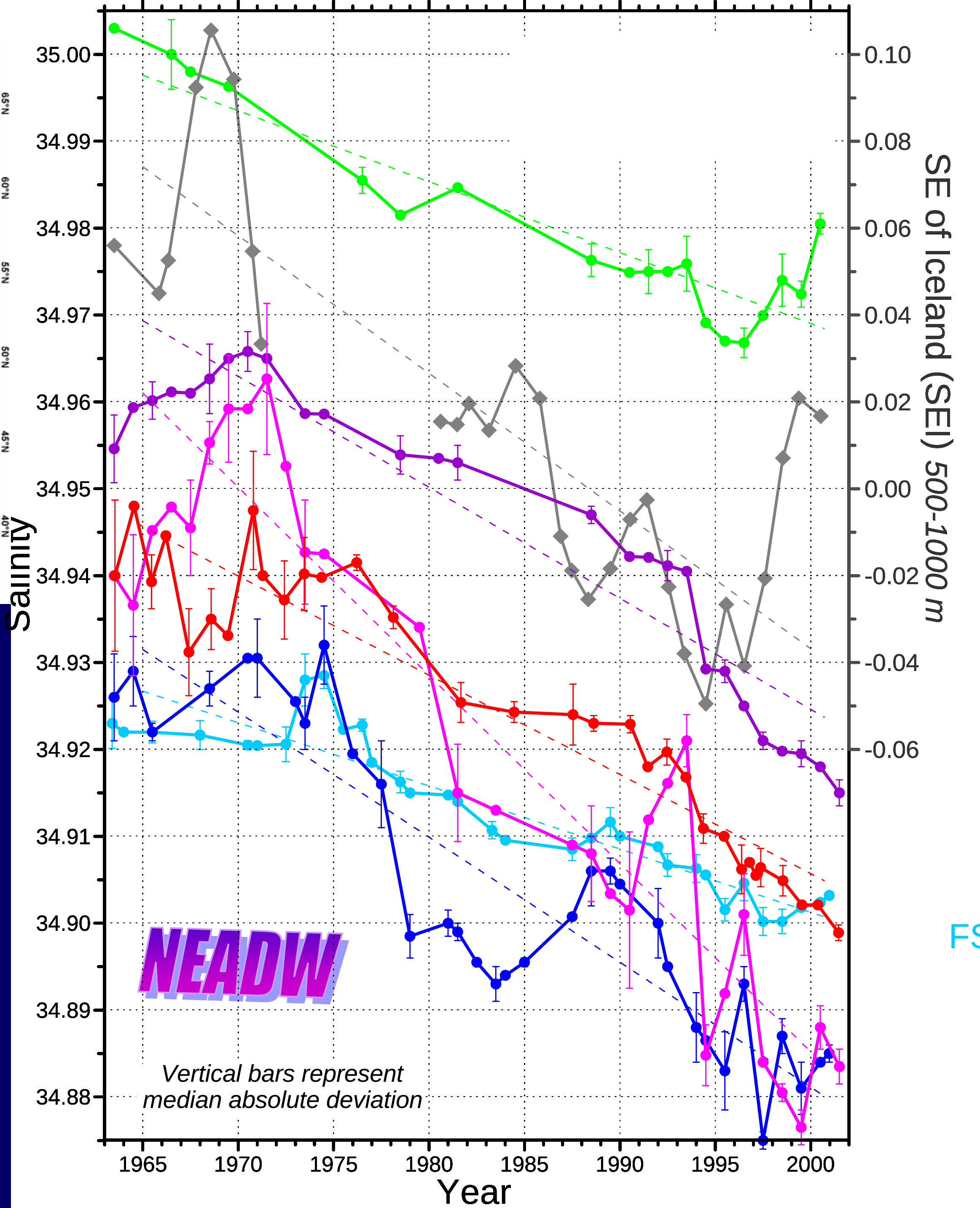
(Levitus et al., 2000)

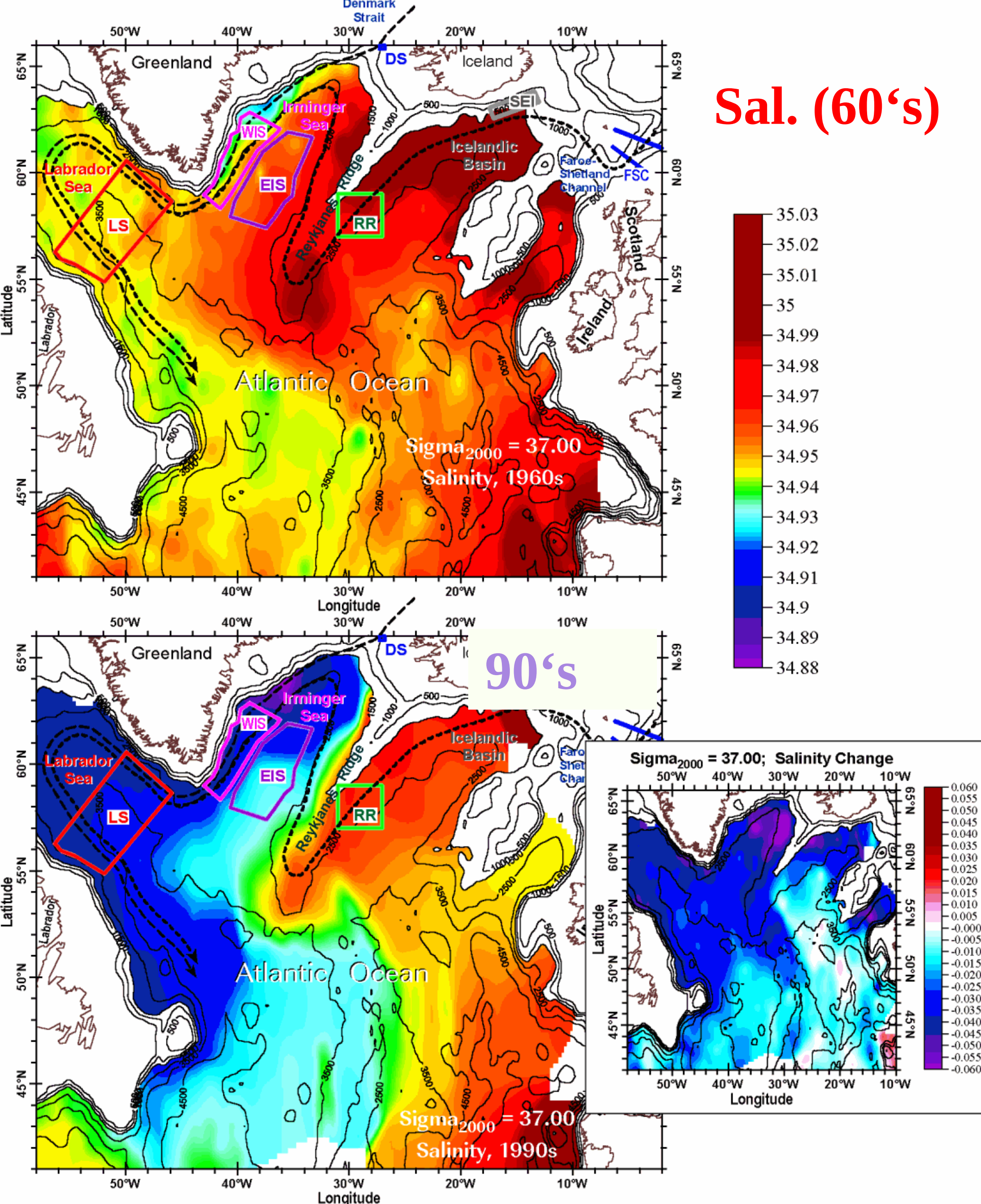


Freshening of Deep Water observed

Sign of enhanced hydrological cycle?

(Dickson et al 2002)





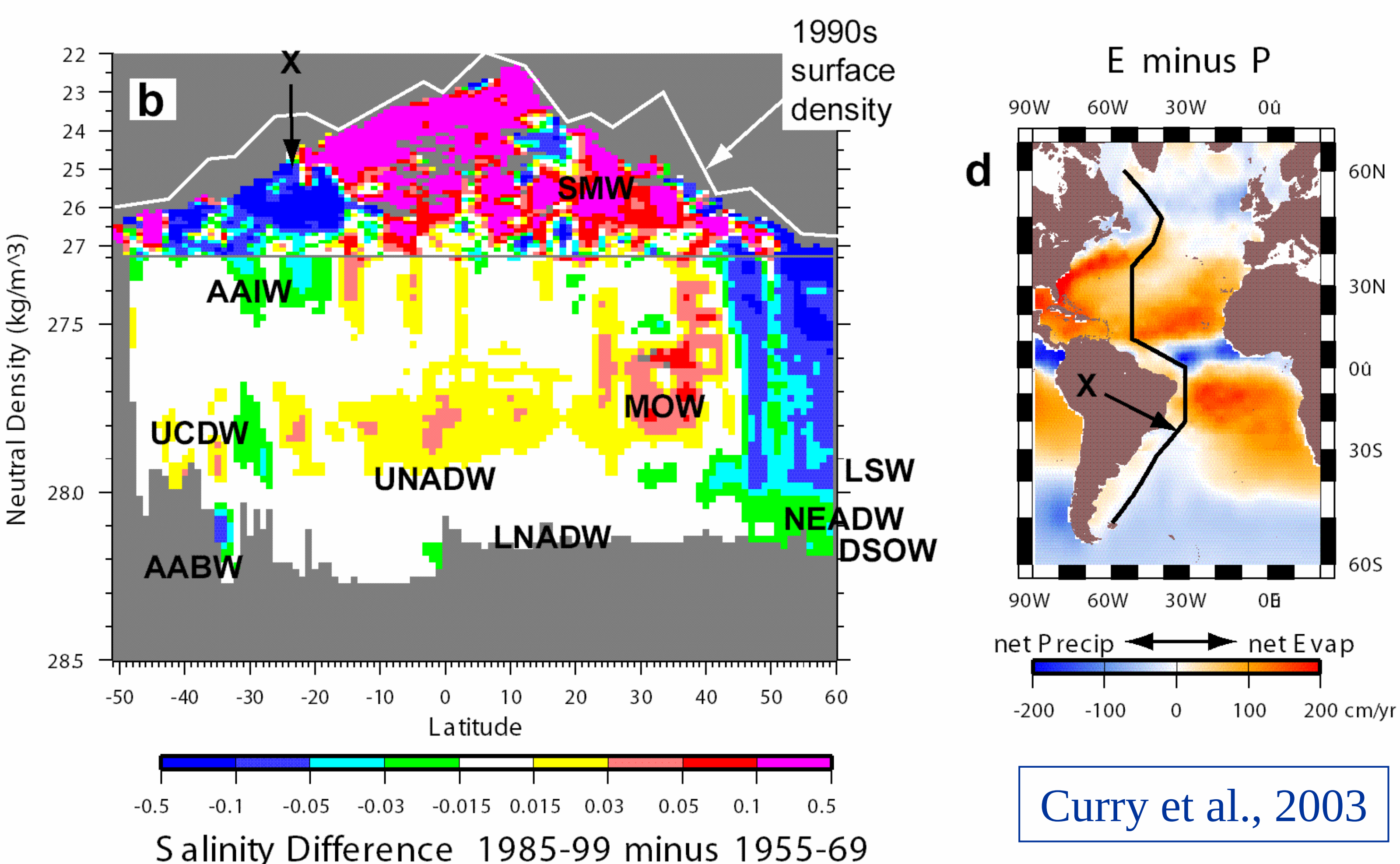
Salinity decrease 1960‘ies to 1990‘ies

at NEADW GFZW level (σ_2 =37.00)

Widespread freshening of the deep (western) basin. Most likely due to increase fresh water export from the Arctic.

I.Yashayaev
pers. com.

Observed Salinity Changes in the Atlantic Sector



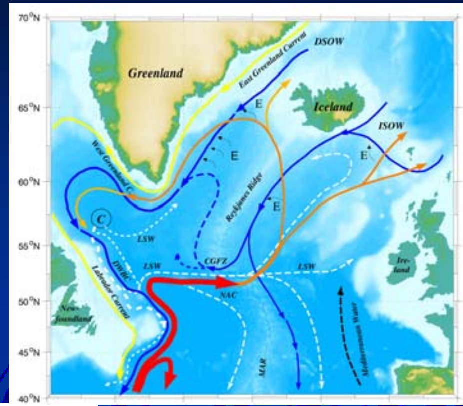
Curry et al., 2003

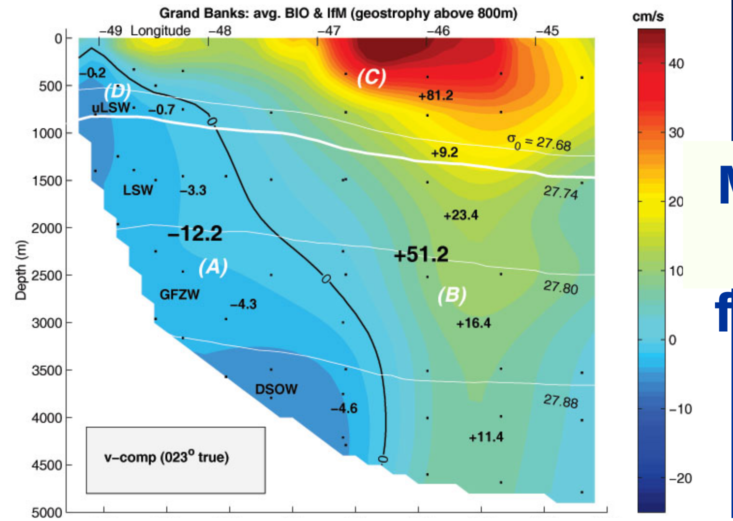
The increase salinity in the Subtropics and decrease in the high latitudes points to an increased hydrological cycle.

This signal is consistent with expected „greenhouse“ scenarios

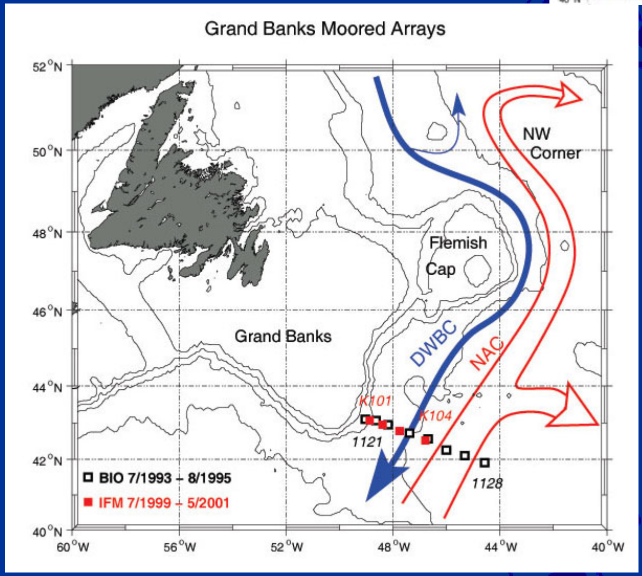
Boundary current at the Grand Banks

Time series of deep water export

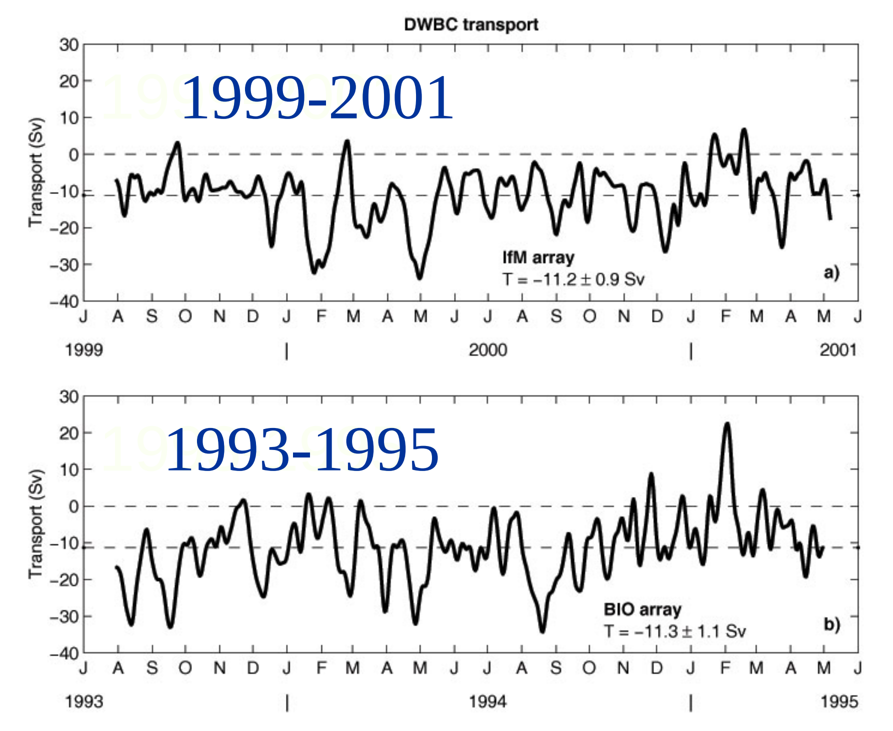




Mean flow



Schott et al., 2003



No significant difference between the two periods

Point 4

• Climate variability in the North Atlantic is complex.

• A significant part it is associated with changes in atmospheric conditions such as the North Atlantic Oscillation.

• Other parts are associated with the state of the ocean and its variable circulation. However, it remains difficult to discern trends.

• RESEARCH IS STILL NEEDED!

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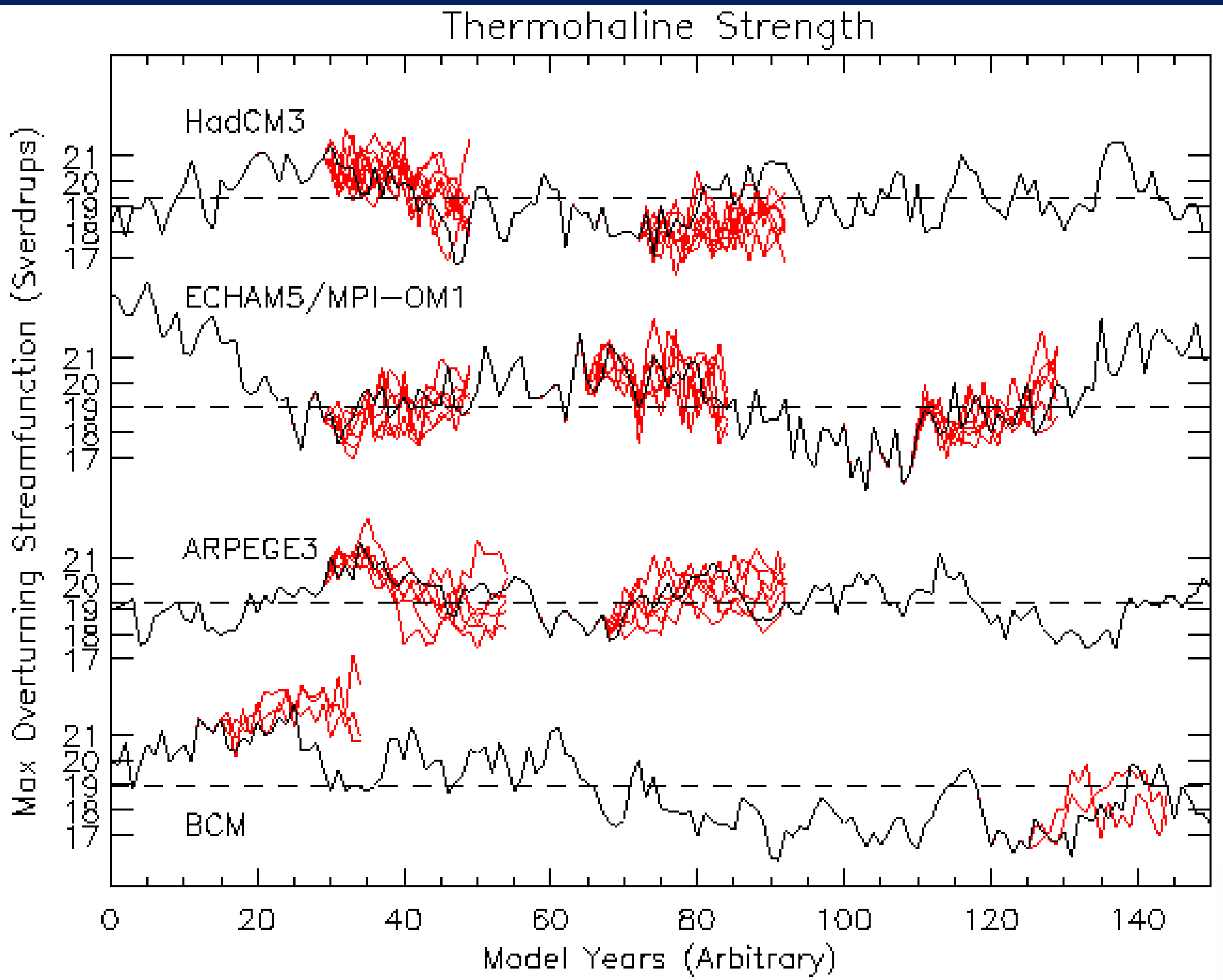
- Where is the Predictability?
- Challenges for the future

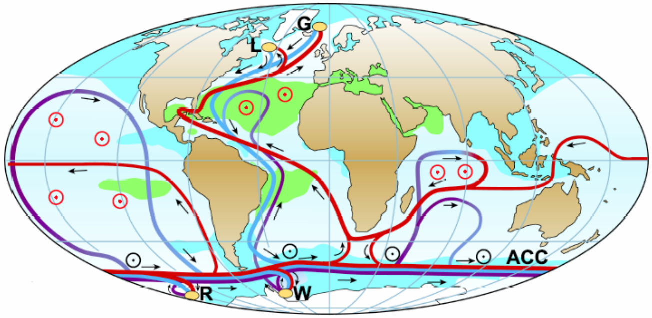
Decadal Predictability of the MOC in models



Control simulations

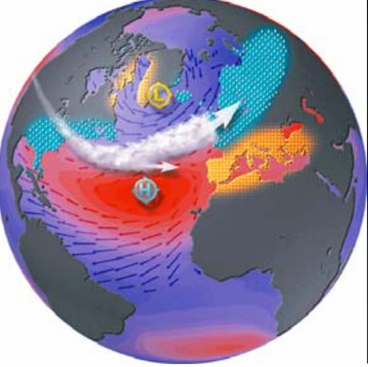
Perturbed runs

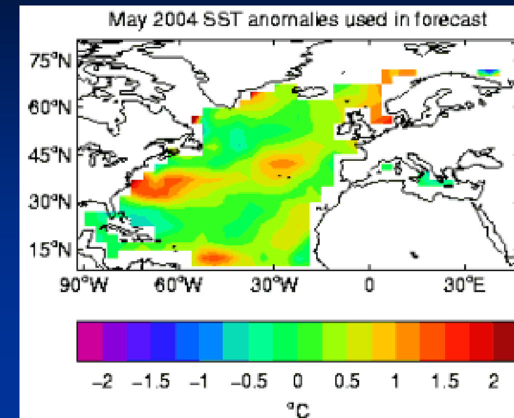
Models suggest predictability on decadal time scales

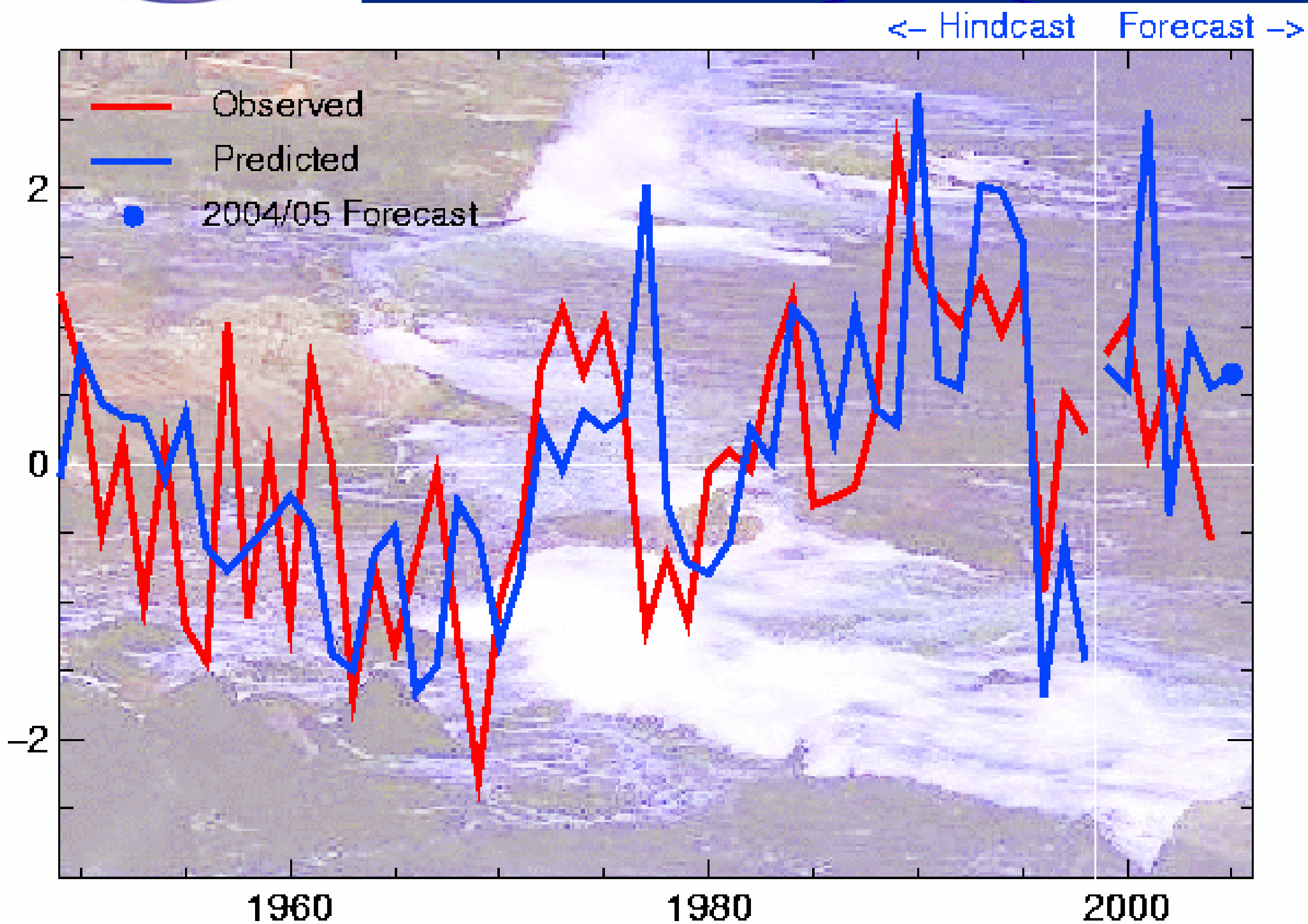


Source: PREDICATE / Mat Collins, CGAM

SST based NAO forecast for 2004/5





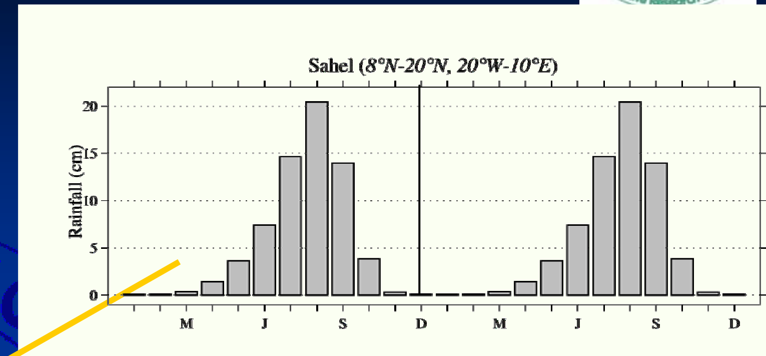


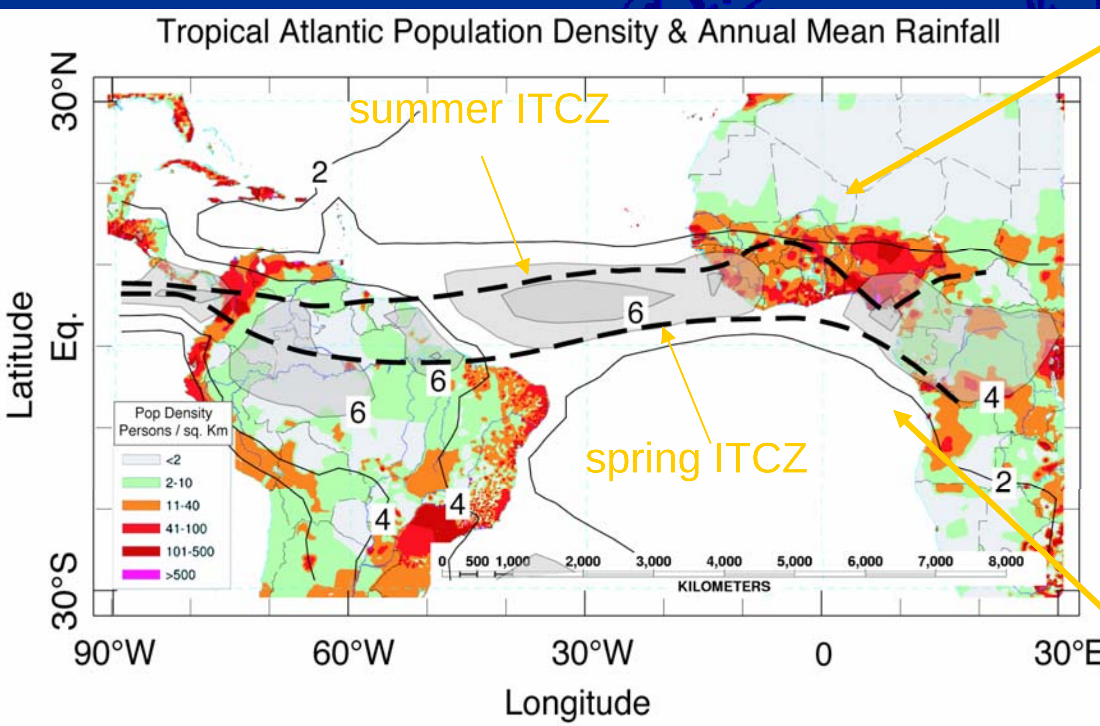
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Taking the observed SST anomaly for May and calculating how it projects onto the predictor pattern we can make a forecast for the winter NAO. Our definition of the NAO is slightly different from the simple difference in surface pressures between the Azores and Iceland but the two time-series are quite similar with a correlation of 0.89.

Atlantic Marine ITCZ

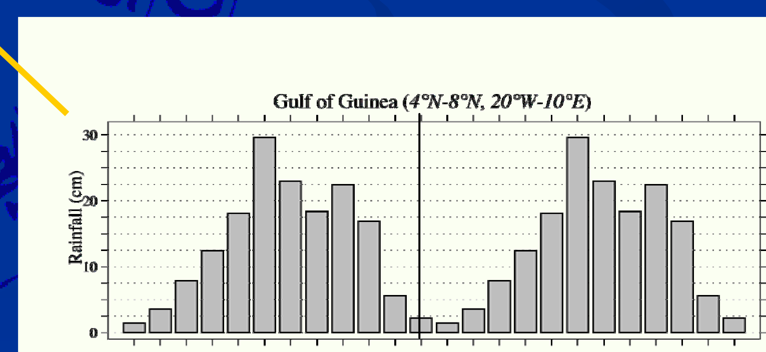
Sahel rainfall climatology



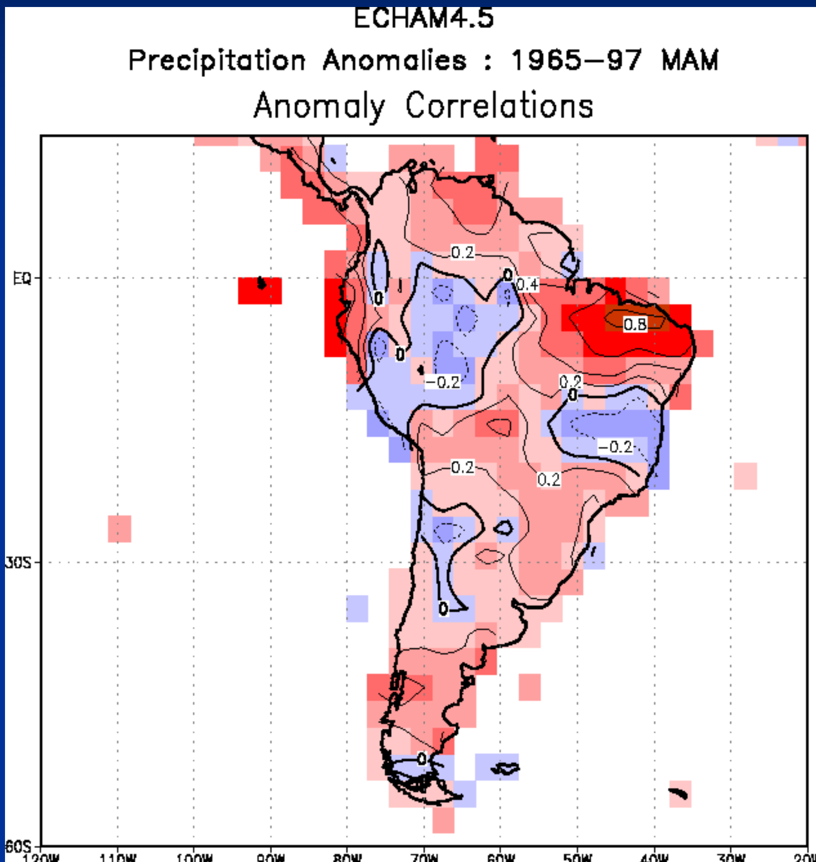


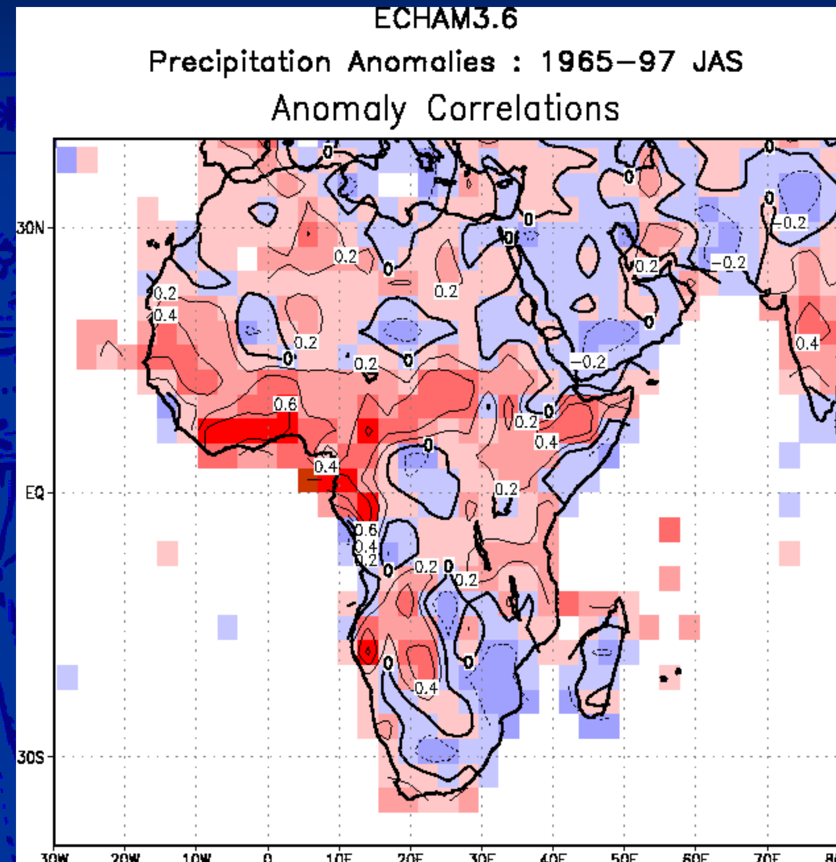
ITCZ position and rainfall intensity affect densely populated regions in West Africa

Guinea rainfall climatology



Tropical Atlantic rainfall variability is POTENTIALLY predictable





Results from perfect SST "AMIP" ensembles (*L. Goddard, IRI)*

… but current seasonal SST forecasts are without skill!

Outline

- Background
- Observed variability and change in the Atlantic Sector
- Where is the Predictability?
- Challenges for the future

Challenges / Priorities

- Complete and sustain a global environmental observing system.
- Build an seamless decision support system from observations to models to products.
- To document and attribute observed changes and variability.
- Realize the seasonal predictability of climate in the tropical Atlantic region.
- To take the lead in the development of decadal climate prediction.

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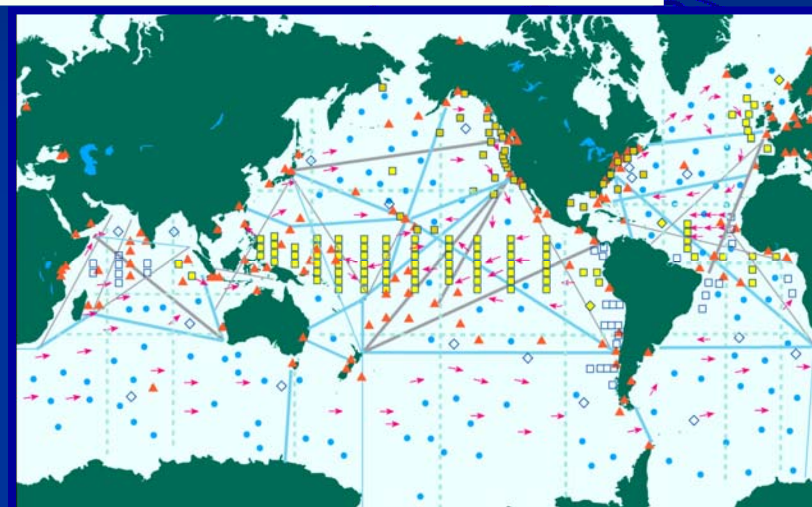
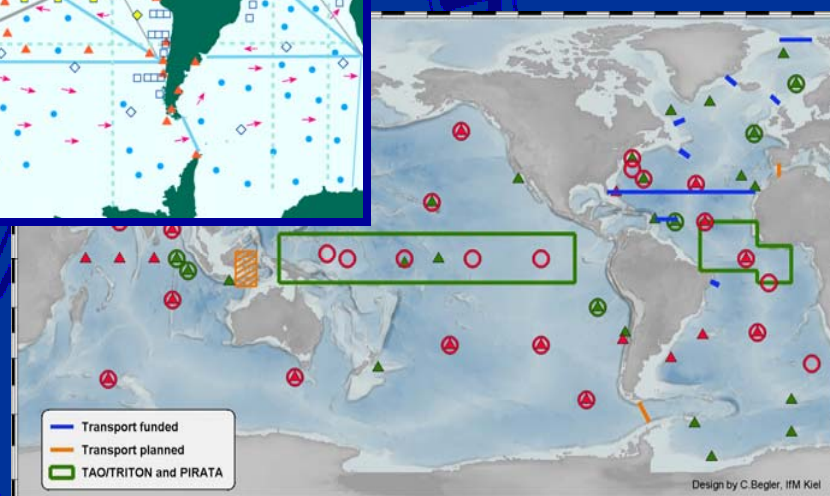
International networks of sustained Global Ocean Observations

CLIVAR

GROUP ON EARTH OBSERVATIONS



Planned time series observations under OceanSITES (Co-Chairs U.Send, R.Weller)



Germany needs to be a strong partner in GEO to build and sustain a

Global Environmental Observing System of Systems (GEOSS)

ARGO Project with the goal of 3000 profiling floats sustained

Ocean Observing Systems

Why do WE need a large scale ocean observing system?

- Improve our understanding of the time varying large scale ocean circulation.

- Provide real time estimates of the ocean state for a large range of applications.
- Initial condition for interannual - decadal predictions (including the ecosystem).
- Improve the performance of ocean and climate models (model - data comparison).

New Ocean Observing Systems

Goal

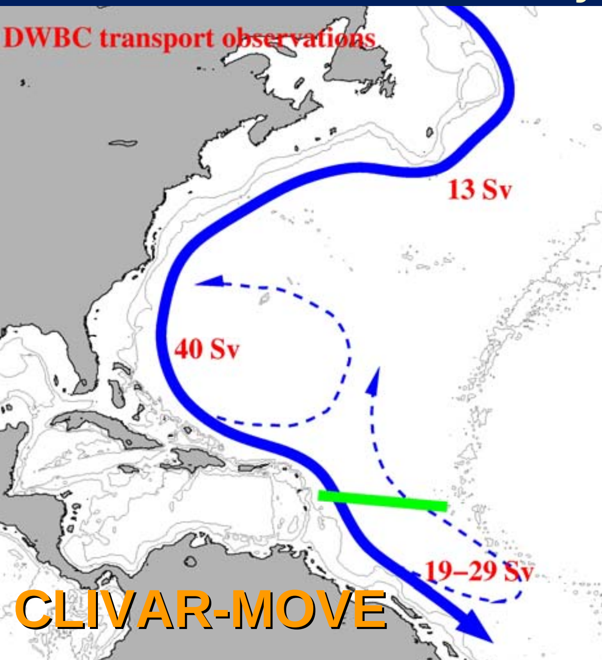
- Observe the ocean in a cost effective manner

Objectives

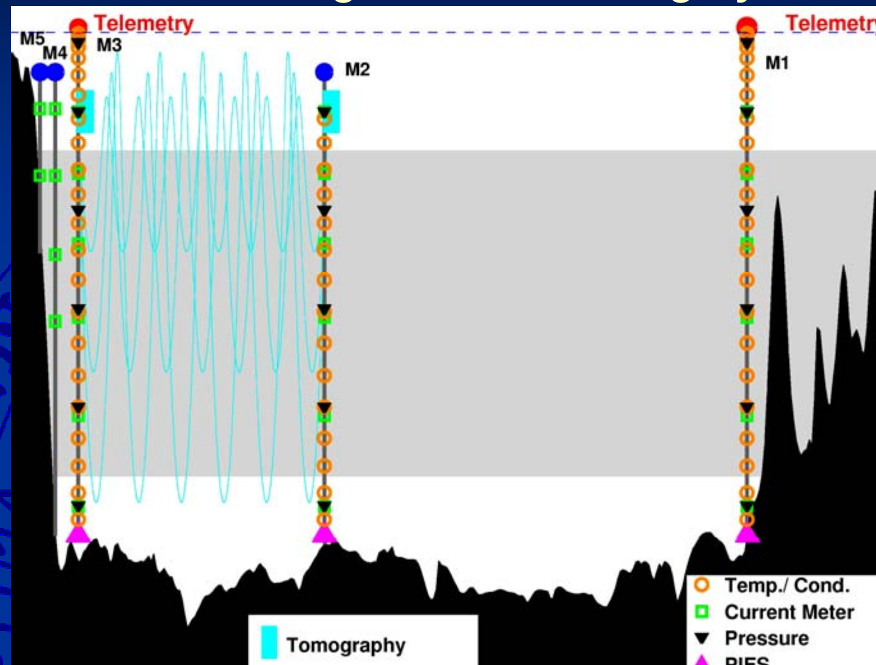
- Versatile platforms
- Novel Sensors
- Improved Communication
- System integration and optimization

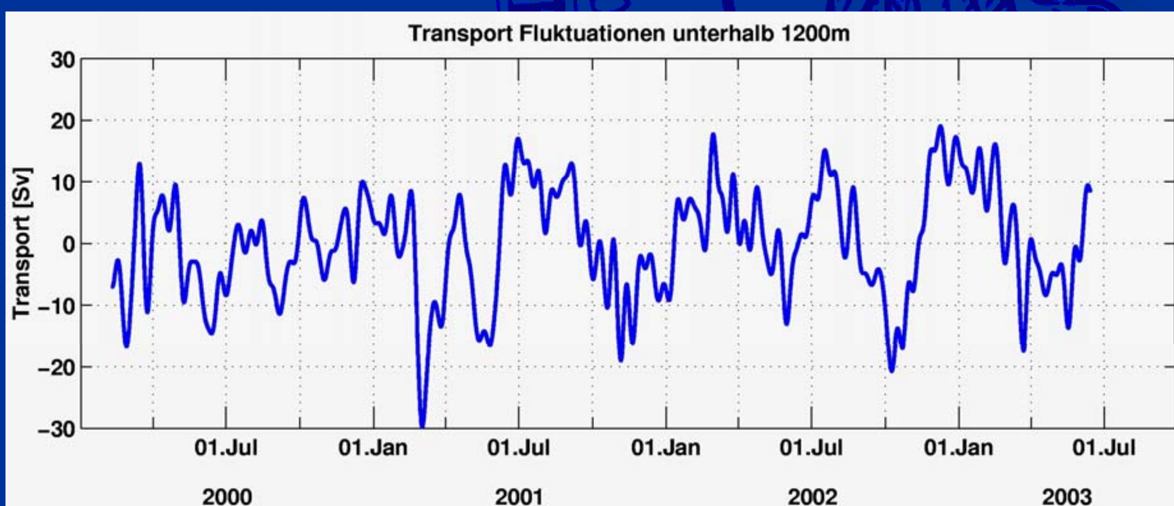
Modern Mooring Technology

Ocean Circulation Variability



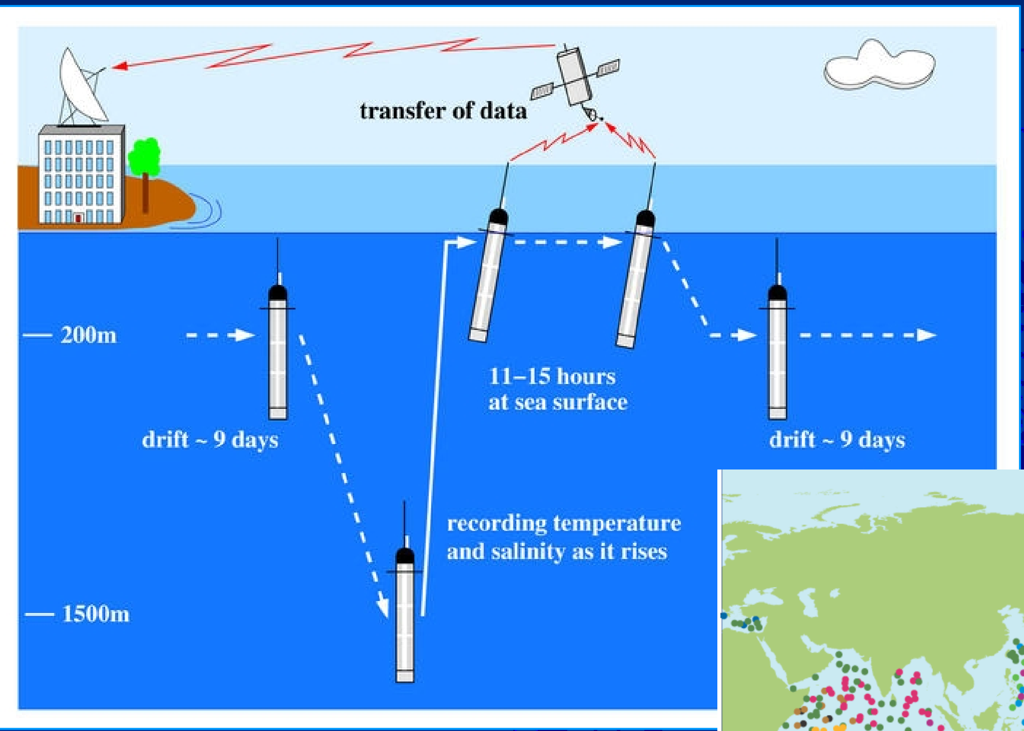
Integrative Observing Systems

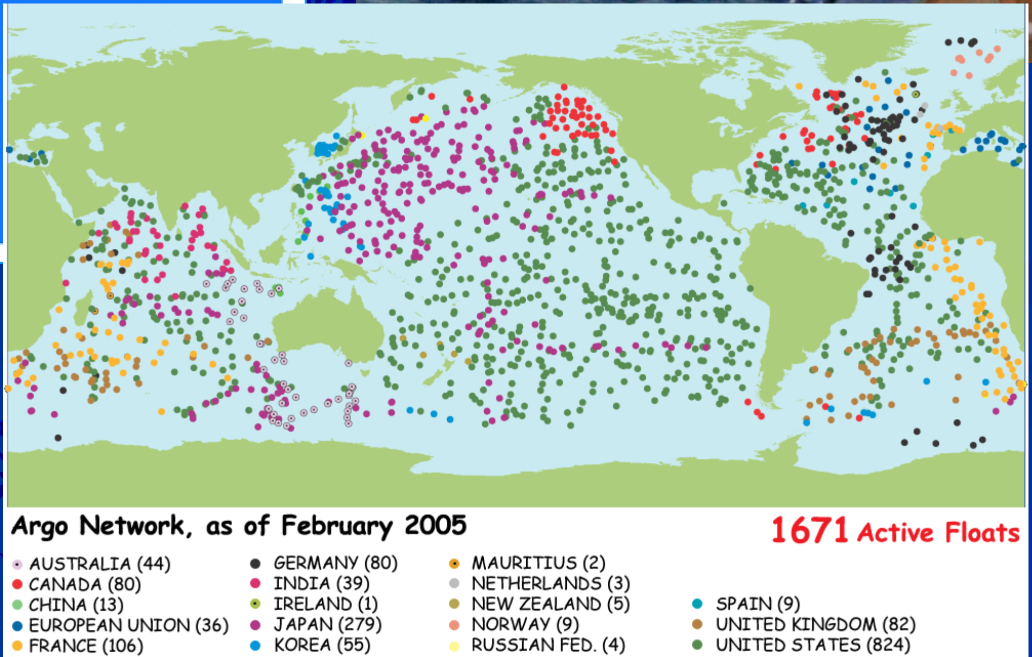




Large array of carefully calibrated instruments, acoustic tomography, bottom pressure gages, real time telemetry

ARGO -- a global network of profiling floats

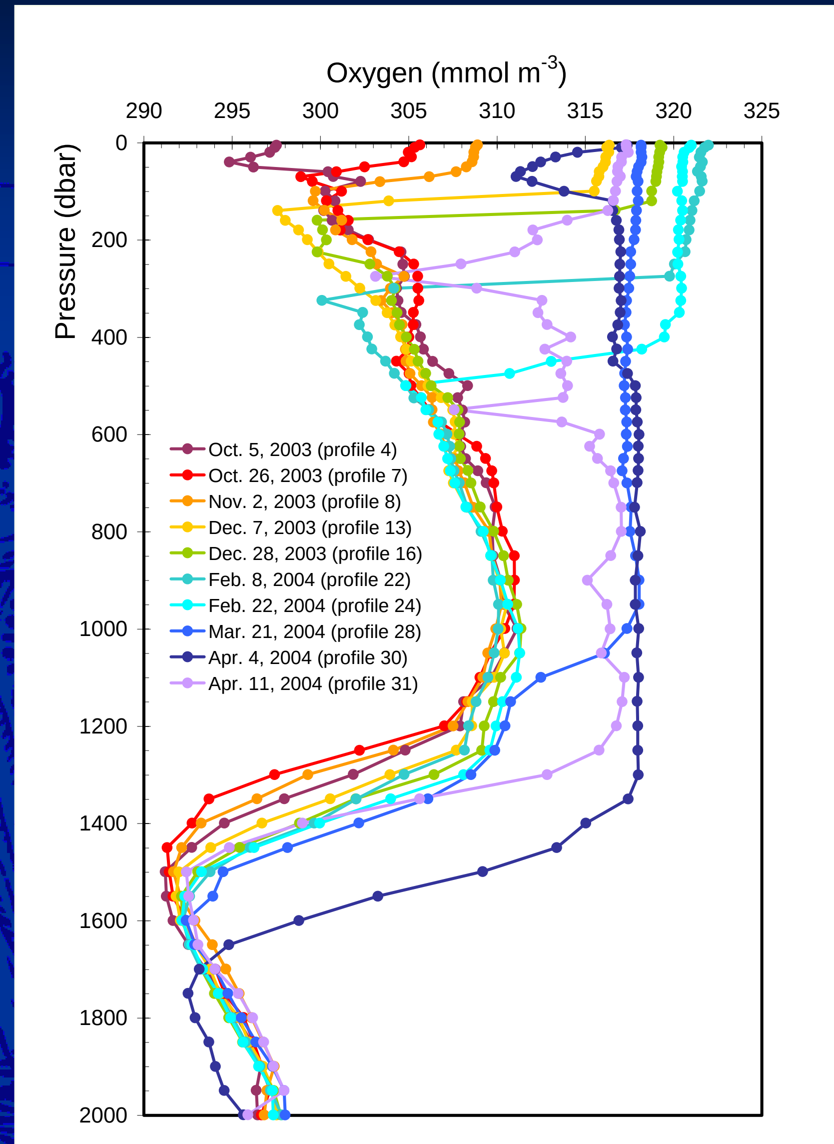




80 German floats

funded by BMBF in a “pilot phase”

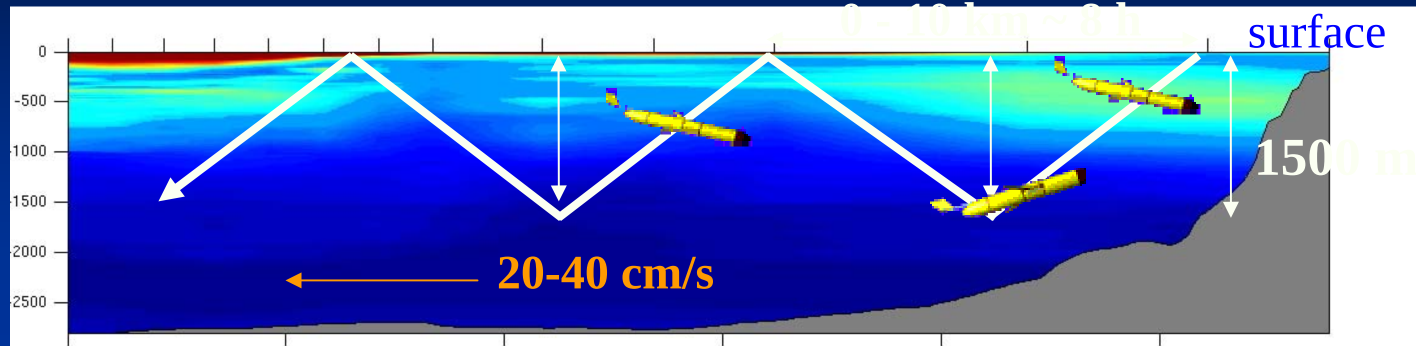
Oxygen measurements from floats



Körtzinger, A., J. Schimanski, U. Send (2004). High-quality oxygen measurements from profiling floats: A promising new technique, *J. Atm. Ocean. Techn.*, in press.

Körtzinger, A., J. Schimanski, U. Send, D.W.R. Wallace (2004). The ocean takes a deep breath. *Science*, in press.

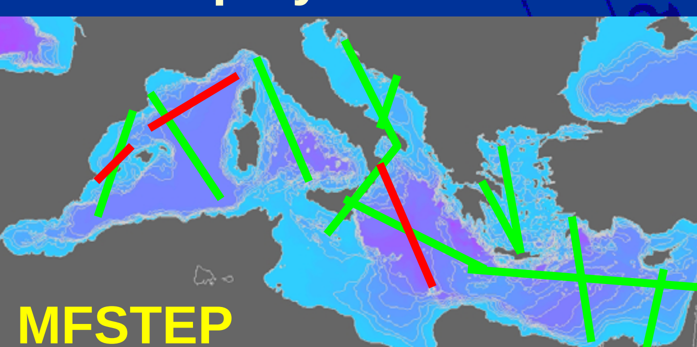
Autonomous Ocean Glider



- Profile the upper 1500m twice a day
- Communicate results in real time
- Last up to 6 month
- Carry a host of electrical sensors

The next big revolution in oceanography!

Trial Deployment



Point 5

- New in-situ and space borne systems allow for cost effective regional and global observations

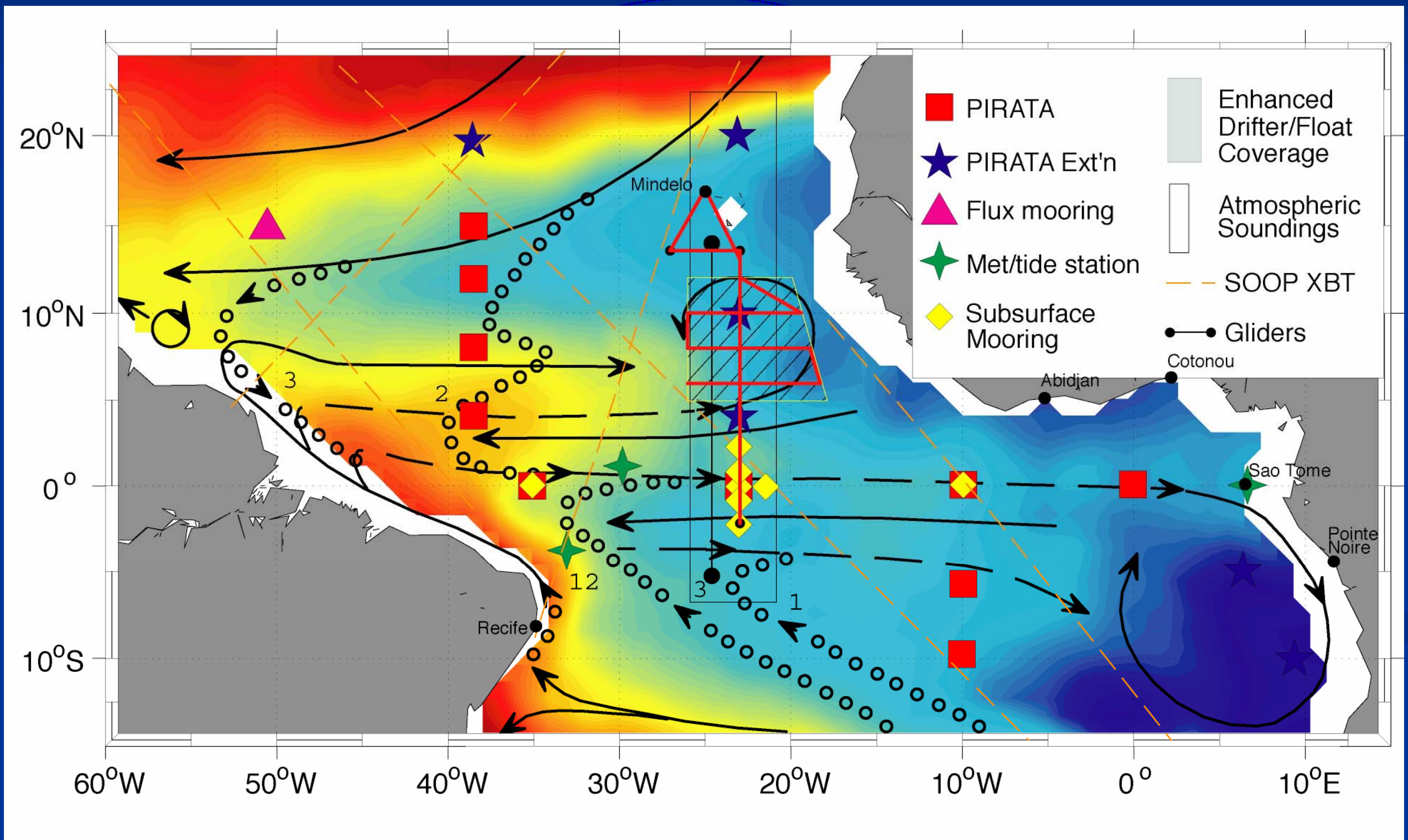
- No system is perfect and can deliver everything that is needed

- No nation can afford this alone

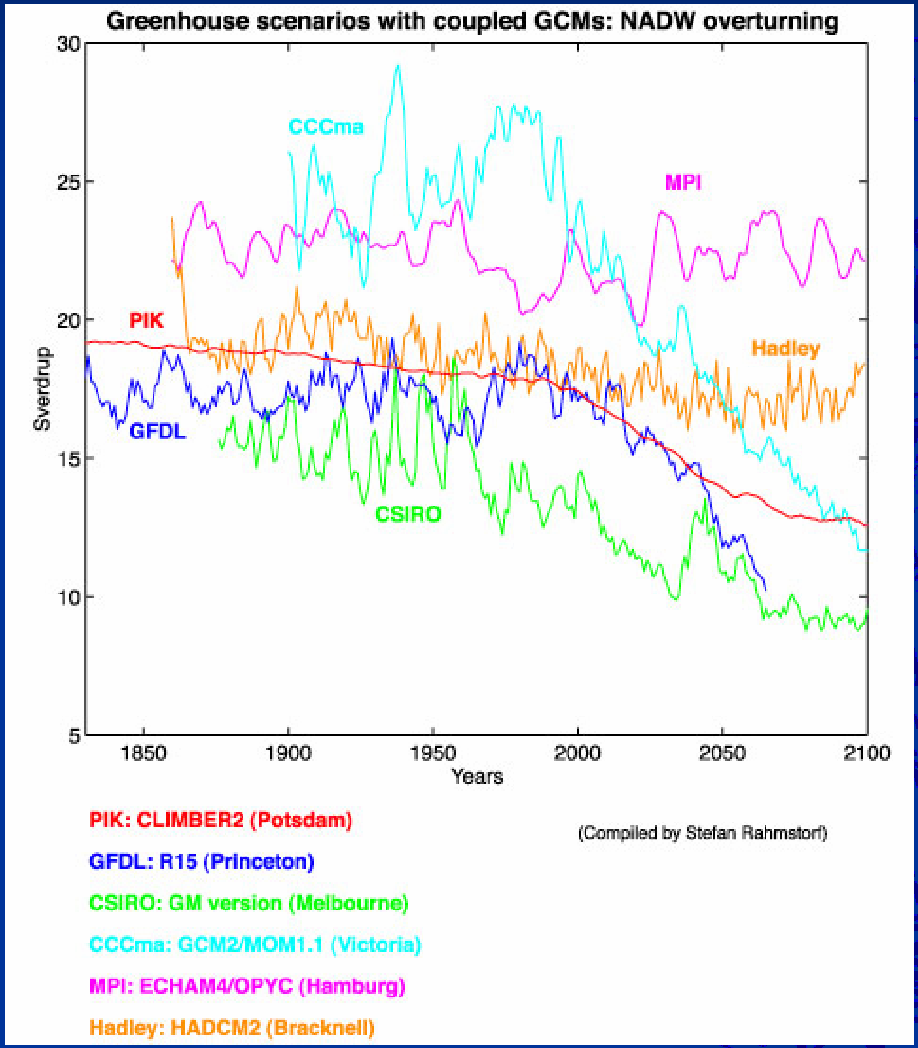
- SUPORT an International System of individual observing Systems

Tropical Atlantic Climate Experiment

Enhanced Observations in the Tropical Atlantic to realize the potential predictability of the ITCZ



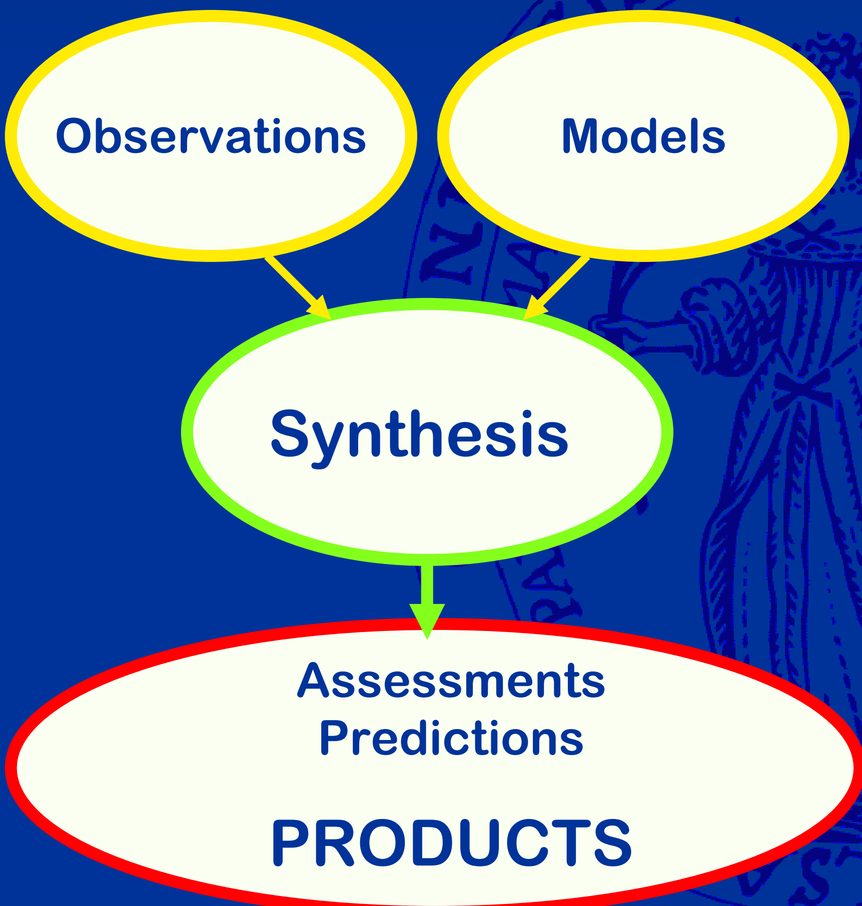
Future scenarios of the Atlantic overturning circulation ?



Recent model studies which investigated climate change over the next century in response to anthropogenic (man-made) climate forcing (e.g. through fossil fuel burning, deforestation, etc.) show that North Atlantic Deep Water formation might respond to global warming by a reduction of its present strength.

Reduce uncertainties of scenario estimates by improving the climate models

Synthesis / Products



Strengthen by international cooperation:

- Data integration
- Model Performance
- Synthesis system
- Stakeholder involvement

in order to fully accomplish the benefits for society

Summary

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- Need to invest in the future by increasing environmental observations (GEOSS)
- Jointly develop useful climate PRODUCS